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TECHNICAL NOTE 2968

PROPELLER-NOISE CHARTS FOR TRANSPORT AIRPLANES

By Harvey H. Hubbard

Langley Aeronautical Laboratory
Langley Field, Va.

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June 1953

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Page 9, equation (1): The power term $\frac{P_H}{c(0.8M_t)^2}$ should be multiplied by the factor 550, so that this equation reads:

$$p = \frac{169.3mBDM_t}{2sA}\left[\frac{550P_H}{c(0.8M_t)^2} - T \cos \beta\right] J_{mB}(x) \tag{1}$$

The text following this equation should also be amended to include the following explanation:

The pressures given by equation (1) are free space pressures and for purposes of this paper were doubled to account for ground reflection.

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SUMMARY

Calculations of rotational-noise and vortex-noise levels at a distance of 300 feet for engine ratings of 1,000 to 10,000 horsepower have been made for a large number of propellers in static operation. Propellers with three, four, six, and eight blades and diameters of 8, 12, 16, and 20 feet are considered. The results are presented in chart and table form for rapid estimation of the noise levels and spectrums in the range of tip Mach numbers from 0.40 to 1.00. Applications of the data to tandem and dual-rotating configurations are given and the supersonic-type propeller is also briefly considered.

It is emphasized that, if noise reductions are to be obtained or if present noise levels are to be maintained for higher power ratings, future propeller designs should operate at lower tip Mach numbers than are currently being used. Single- rather than dual-rotating propellers were found to generate the lowest over-all noise levels for a given number of blades.

INTRODUCTION

The principal neighborhood nuisance factor in connection with airports is the noise resulting from ground and flight operations of aircraft. The external-noise problems are currently overshadowing the ever-present problem of proper protection for the passengers and crew. Reference 1 indicates that increasing engine power ratings, greater traffic densities, and greater concentrations of population near airports are combining to intensify the airport noise problem.

Although the possibility is recognized that the operation of jet engines may eventually create another very serious transport-airplane noise problem, the propeller is currently one of the major sources of external noise. As engine power ratings increase, propeller noise levels, in general, will also increase unless a concerted effort is made in the interest of noise reduction. For future propeller aircraft, the adherence to current design trends will probably not be feasible if noise reductions are to be obtained or even if present levels are to be maintained.

References 2 and 3 deal with the noise and performance, respectively, of propellers of personal-owner airplanes. The present paper and reference 4, which cover approximately the same ranges of propeller parameters, are essentially extensions of the studies of references 2 and 3 to propellers of transport airplanes. Information in regard to noise levels is presented in the present paper to enable the designer to evaluate new configurations in the early design stage and to evaluate the benefits from possible modifications to existing configurations.

SYMBOLS

M_t	rotational tip Mach number
$V_{0.7}$	section velocity at the 0.7-radius station, fps
A	propeller-disk area, sq ft
A_B	propeller-blade area, sq ft
N	propeller rotational speed, rpm
s	distance from propeller to observer, ft
B	number of blades
T	thrust, lb
P_H	power input to propeller, hp
D	propeller diameter, ft
I	sound-pressure level, db, re 0.0002 μbar
$\bar{I}$	over-all sound-pressure level, db,
$\bar{I}_V$	sound-pressure level of vortex noise, db
$\bar{I}_R$	sound-pressure level of rotational noise (summation of first four harmonics), db
p	root-mean-square sound pressure of a given harmonic, dynes/sq cm
$J_{mB}(x)$	Bessel function of order mB and argument $x = 0.8M_t mB \sin \theta$
β	angle between propeller axis of rotation and line from center of propeller to observer (ranges from 0° in front of propeller to 180° behind it), deg

C_P power coefficient, $550P_H \Big/ \rho\left(\frac{N}{60}\right)^3 D^5$

C_T thrust coefficient, $T \Big/ \rho\left(\frac{N}{60}\right)^2 D^4$

C_L effective lift coefficient, as defined in appendix C, $2T \big/ \rho A_B {V_{0.7}}^2$

c sound speed, fps

k, k' constants of proportionality

m order of harmonic

ρ air density, slugs/cu ft

f frequency, cps

Subscripts:

1, 2, 3, 4 number of the harmonic

ESTIMATION OF PROPELLER NOISE

General Considerations

Most external-noise problems result from static operation of aircraft or from take-off and landing operations. The aircraft in these operations is relatively close to the observer and, in the take-off condition particularly, is using maximum power. For the purposes of the present paper, the noise for various transport propeller configurations has been calculated for static conditions. These results may also be assumed to apply approximately to conditions of low forward speed as in take-off and landing.

Noise from propellers consists of a rotational component and a vortex component. The rotational component is due to the steady aerodynamic forces on the propeller blade, whereas the vortex component results from the shedding of vortices from the propeller blade. Since the laws of generation of these two components are different, they may vary in importance as the operating conditions of the propeller change and also as the configuration changes. These effects are illustrated qualitatively in figure 1, which also indicates the nature of these two noise components. Figure 1(a) is a noise spectrum of a propeller operating near a tip Mach number of 1.0. For this condition, the major contribution is from the rotational component. The spectrum consists of several discrete frequencies which are harmonically related to the blade passage frequency and are of constant amplitude.

Figure 1(b) is the vortex-noise spectrum from a rotating circular rod and illustrates the nature of vortex noise from propellers. This noise is random and has a continuous spectrum over a range of frequencies determined by the section velocity and geometry. The frequencies are associated with the Kármán vortex street in the wake and may be predicted by the Strouhal relation as given in reference 5. The maximum intensity in figure 1(b) corresponds to the Strouhal frequency in the wake of the blade at its half-radius section. In the case of a propeller, the vortex-noise spectrum will usually be broader than that of figure 1(b) because of the variation in blade thickness along the span.

For the case in which a propeller operates at a low rotational speed, the rotational and vortex components may be of the same order of magnitude; if they are, the type of spectrum shown in figure 1(c) results. In general, the vortex component has a higher frequency content than the rotational component and increases in intensity at a slower rate as a function of tip speed. As a result, high- and low-tip-speed propellers will have quite different noise spectrums. The vortex component is assumed to be most intense on the axis of rotation in front of and behind the propeller plane ($\beta = 0^{\circ}$ and $\beta = 180^{\circ}$), whereas the rotational component is usually a maximum at values of azimuth angle β between 90° and 120°.

Charts and Tables

Calculations of propeller rotational- and vortex-noise levels have been made by the methods outlined in appendixes A and B and in accordance with the simplifying aerodynamic assumptions of appendix C. Intensities and frequencies of the first four rotational harmonics, as calculated for a distance of 300 feet by the method of Gutin (ref. 6) in appendix A, are listed in table I for a wide range of propeller parameters. Figures 2 to 7 give the rotational- and vortex-noise levels as functions of tip Mach number for propellers of three, four, six, and eight blades and for engine ratings of 1,000, 2,000, 4,000, 6,000, 8,000, and 10,000 horsepower. The rotational-noise values, plotted as the solid-line curves in these figures, were obtained by a summation of the noise from the first four rotational harmonics as listed in table I. In order to estimate the noise levels for two and four propellers in random phase, the values given in figures 2 to 7 should be increased by 3 and 6 decibels, respectively.

Vortex-noise levels, presented in figures 2 to 7 as the dashed lines, were estimated by means of the method outlined in appendix B, which is based on reference 7. The vortex-noise levels for a given propeller are higher for the stalled condition than for the unstalled condition. The levels of figures 2 to 7 are calculated for the unstalled condition and hence may be as much as 10 decibels too low for some operating conditions.

Single-rotating propellers.- The data presented in table I and in figures 2 to 7 are directly applicable to single-rotating propellers. A special type of single-rotating propeller is the tandem configuration which consists of two stages of blades having the same thrust axis and direction of rotation. On the basis of the results of reference 6, the noise field from this configuration is believed to be approximately the same as for a conventional single-rotating propeller with the same number of blades and with the same angular blade spacing.

Dual-rotating propellers.- The data of figures 2 to 7 may also be used to estimate the noise from dual configurations with the aid of figure 8. The noise from a dual-rotating propeller may be determined from the noise fields of both of its component propellers (ref. 8). Figure 8 has been prepared to illustrate the manner in which these noise fields add up. The noise from a propeller has been shown to be independent of its direction of rotation and hence, in the dual-rotating case, the instantaneous phasing of the blades determines the nature of the sound field generated. This phenomenon is illustrated in figure 8, in which the radiation pattern is shown by the solid line for a four-blade dual-rotating propeller and by the dashed lines for a two-blade single- and a four-blade single-rotating propeller. The two stages of blades of the dual-rotating propeller are geared so that the blades overlap on axes AA' and BB' and are equally spaced along axes CC' and DD'. The sound intensity is a maximum on the overlap axes where the propeller appears to the observer as a two-blade propeller and is a minimum on the axes where it appears as a four-blade propeller. In addition to the change in overall levels as a function of the observer's position, the spectrums also change. On axes AA' and BB' the spectrums have all the harmonics of a two-blade propeller, whereas on axes CC' and DD' the spectrums have only the frequencies of a four-blade propeller.

The intensity variations as a function of the observer's position can be estimated for various dual configurations with a wide range of operating conditions from the data of figures 2 to 7. For example, it can be shown with the aid of figure 4(b) that the noise levels for a six-blade dual-rotating propeller absorbing 4,000 horsepower at a tip Mach number of 0.80 would vary from 111 to 116 decibels depending on the observer's position relative to the overlap axis. The maximum and minimum values correspond to those for a three-blade and a six-blade single-rotating propeller, respectively, at the same power loading as the dual configuration.

Supersonic-type propellers.- The over-all noise from a propeller operating at supersonic tip speeds may be estimated from the curves of figure 9, which have been prepared by extrapolating the measurements of reference 9 to greater distances and to higher powers. The tests of reference 9 indicated that the noise from this type of propeller was a maximum in the plane of rotation, that for a given power loading the noise was essentially independent of tip Mach number in the low supersonic range, and that only a small reduction in noise could be expected from an increased number of blades. Although figure 9 applies directly to a two-blade propeller at a tip Mach number of 1.20, the data of the figure may be interpreted as the maximum noise levels that would be encountered in the low supersonic range of tip speed for any propellers at the appropriate power loadings.

DISCUSSION OF RESULTS

Tip Mach Number

The variation of sound pressure as a function of tip Mach number at a constant power is shown in figures 2 to 7 for various propellers in the subsonic tip Mach number range. These figures show that a reduction in tip Mach number is always beneficial in reducing the noise and that the reductions occur at a faster rate for propellers with a larger number of blades. Since the vortex noise decreases at a slower rate with tip Mach number than the rotational noise, it may become relatively important at the low tip Mach numbers. In that range the propeller noise spectrum may contain a relatively high proportion of vortex noise.

Although the supersonic-type propeller offers certain weight and performance advantages, its use commercially may be greatly limited because of its high noise levels. If any effort is made in the interest of noise reduction, the trend would be toward lower tip speeds than are currently being used rather than toward higher ones.

Number of Blades

An increase in the number of blades is generally beneficial in reducing noise. This principle is well-established for conventional single-rotating propellers and is believed to be equally applicable for tandem configurations with uniform angular blade spacing. The variation of sound pressure as a function of number of blades at a constant power is given in figures 2 to 7 for various tip Mach numbers. In general, the largest noise reductions are obtained at the lower tip Mach numbers and relatively small reductions are obtained at the higher ones. In the tip Mach number range, where the vortex noise may be an appreciable part of the total, however, an increase in the number of blades may result in little or no over-all noise reduction.

Dual-rotating propellers have unique directional patterns which tend to minimize the benefits from an increased number of blades. Figure 8 shows, for example, that an eight-blade dual propeller has eight maximums and eight minimums in its radiation pattern. As the number of blades increases, the maximums and minimums are spaced closer together and hence it becomes more difficult to derive benefits from these directional effects. As a result of this nonuniform noise field, a small change in the orientation of the propeller with respect to the observer may cause a rather large change in the level of noise at the observer's position. The magnitude of this variation in noise level is a function of the propeller tip Mach number, and for a tip Mach number of 0.50 this variation would be of the order of 20 decibels for the conditions of figure 5(c). An observer inside the airplane would normally not be subjected to this intensity variation since the orientation of the propeller with respect to the airplane is fixed. This phenomenon would be especially annoying to observers on the ground during maneuvering flight at low altitudes.

Power Loading

The power loading of the propeller is a function of both the power input to the propeller and the propeller diameter; figure 10 shows that the noise generated is a function of both of these parameters. For any given propeller diameter the sound levels are seen to increase by approximately 5 to 6 decibels as the power is doubled. This finding is general and applies approximately to all tip speeds.

An apparent discrepancy arises when the power loading is changed by changing the diameter of a propeller. Figure 10 indicates, for instance, that a halving of the diameter for a given power increases the sound levels by 5 to 6 decibels, whereas a 10 to 12 decibel increase would be expected solely on the basis of a resultant quadrupling of the power loading. Two effects are involved one of which partially compensates for the other. A halving of the diameter effectively doubles the distance from the observer to the source and thus tends to neutralize the effect of increased power loading. For a given power input the use of as large a diameter as possible to reduce the power loading to a minimum is advantageous.

CONCLUDING REMARKS

Information with which to estimate the noise from propellers of transport airplanes for various operating conditions has been presented. It is emphasized that, if noise reductions are to be obtained or if present noise levels are to be maintained for higher power ratings, future propeller designs should operate at lower tip Mach numbers than are currently being used. Single- rather than dual-rotating propellers were found to generate the lowest over-all noise levels for a given number of blades.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 18, 1953.

APPENDIX A

CALCULATION OF ROTATIONAL NOISE

Rotational-noise values of the present paper have been calculated by the method of Gutin in reference 6, which has been confirmed by the experiments of reference 9. The Gutin equation in a form convenient for engineering use is as follows:

$$p = \frac{169.3mBDM_t}{2sA}\left[\frac{P_H}{c\left(0.8M_t\right)^2} - T\cos\beta\right]J_{mB}(x) \qquad (1)$$

The sound pressure p corresponding to a given harmonic is thus seen to be a function of the power P_H, tip Mach number M_t, number of blades B, propeller diameter D, propeller-disk area A, and azimuth angle of the observer β. For the purposes of this paper, β was assumed to be 105° since that value corresponds to the angle of maximum radiation for most of the propeller configurations considered. Calculations were made for a distance s of 300 feet, a sound speed c of 1,126 feet per second, and values of thrust T which were estimated by the method of appendix C.

Calculations of the sound pressure p for values of mB corresponding to the first four rotational harmonics have been made and converted to sound-pressure levels. These values are given in table I along with the corresponding frequencies for various combinations of propeller tip Mach number, number of blades, and power input. Summations have been made by taking the square root of the sum of the squares of the pressures of the first four harmonics and these results, after conversion to levels $\bar{I}_R$ in decibels, are plotted as the solid-line curves in figures 2 to 7.

APPENDIX B

CALCULATION OF VORTEX NOISE

Vortex-noise levels were calculated by a method based on the work of Yudin in reference 7. For rotating rods having airfoil sections, as well as for those having circular cross sections, the vortex-noise energy was concluded to be proportional to the first power of the blade area and to the sixth power of the section velocity. Thus the following equation was used to calculate the vortex-noise levels in decibels for figures 2 to 7:

$$\bar{I}_V = 10 \log_{10} \frac{kA_B V_{0.7}^{\;6}}{10^{-16}} \qquad (2)$$

where k is the constant of proportionality evaluated tentatively as 3.8×10^{-27} in the work of reference 2.

A plot of the vortex-noise levels as a function of blade area for a range of tip Mach number is given in figure 11. Figure 11 is a summary of the vortex-noise levels plotted as the dashed curves of figures 2 to 7 and should be considered tentative pending further experimental confirmation.

APPENDIX C

ESTIMATION OF STATIC THRUST AND PROPELLER-BLADE AREA

In order to make calculations of the noise levels generated by various propeller configurations by means of equations (1) and (2), some of the interrelated aerodynamic and geometric parameters must be known. Some simplifying assumptions were made in order to expedite the calculation of static thrust and propeller-blade area. Although they are not considered adequate for aerodynamic studies, the resulting equations are considered satisfactory for the purposes of this paper.

Figure 12 gives C_P per unit horsepower as a function of tip Mach number for various propeller diameters. For any other power rating, C_P is easily obtained by multiplying the ordinate of figure 12 by the horsepower. For given values of C_P, D, and M_t the associated static thrust for use in equation (1) was determined from figure 13. The thrust calculations of figure 13 made use of the relation

$$C_T = k'C_P^{2/3}$$

where k' is a constant of proportionality evaluated as 0.75. This value was chosen on the basis of experimental results of reference 10 and appears to be valid for propellers operating near the stall.

From the expression for differential thrust given in reference 11, the following equation, which assumes that the lift is approximately equal to the thrust, may be derived:

$$A_B = \frac{2T}{\rho C_L V_{0.7}^2}$$

For the purposes of this paper it is assumed that $C_L = 0.4$, that $\rho = 0.002378$ slugs per cubic foot, and that $V_{0.7}$ is the section velocity at the 0.7-radius station. This expression for blade area is evaluated for the ranges of static thrust and tip Mach number of the present studies for use in calculations of vortex noise levels from equation (2).

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TABLE I

CALCULATED SOUND-PRESSURE LEVELS OF THE FIRST FOUR ROTATIONAL-NOISE HARMONICS FOR VARIOUS PROPELLER OPERATING CONDITIONS

[D = 8 feet]

B	M_t	Frequency, cps				Sound-pressure level, db																							
						I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4
		f_1	f_2	f_3	f_4	P_H = 1000				P_H = 2000				P_H = 4000				P_H = 6000				P_H = 8000				P_H = 10,000			
3	0.4	54	107	161	215	94	74	51	24	100	79	57	29	106	85	63	35	109	89	66	39	112	91	69	41	113	93	71	43
	.5	67	134	202	269	96	83	68	50	102	88	73	56	108	94	78	62	111	98	82	65	114	100	85	67	115	102	86	69
	.6	81	161	242	323	100	81	79	67	106	96	85	73	111	102	90	78	115	105	93	82	117	108	96	84	119	110	98	86
	.7	94	188	283	377	103	97	89	80	108	103	95	86	114	108	100	91	117	112	103	95	120	114	106	97	121	116	108	99
	.8	107	215	322	430	106	103	95	92	112	108	100	97	117	114	105	103	120	117	109	106	123	119	111	108	124	121	113	110
	.9	121	242	363	484	109	107	105	101	114	112	110	106	120	118	115	112	123	121	119	115	125	123	121	117	127	125	123	119
	1.0	134	269	403	538	111	111	110	108	117	116	115	114	122	122	121	119	125	125	124	122	127	127	126	124	129	129	128	126
4	0.4	72	143	215	286	85	42	24	—	91	47	29	5	97	53	35	11	100	57	39	14	103	59	41	17	105	61	43	19
	.5	90	179	269	358	91	57	50	28	96	62	56	33	102	68	61	39	105	71	65	42	108	74	67	45	110	76	69	47
	.6	108	215	323	430	97	83	67	50	102	89	73	56	108	95	78	61	111	98	82	64	114	100	84	67	116	102	86	69
	.7	126	251	377	502	101	91	80	69	107	97	86	75	112	102	91	80	116	105	95	84	118	108	97	86	120	110	99	88
	.8	143	286	430	573	106	100	92	83	111	105	97	88	116	111	103	94	120	114	106	97	122	116	108	99	124	118	110	101
	.9	162	322	484	645	107	105	101	96	112	110	106	101	117	116	112	106	120	119	115	110	123	121	117	112	124	123	119	114
	1.0	179	358	538	717	111	110	108	106	116	116	114	111	121	121	119	116	124	124	122	119	127	126	124	122	128	128	126	123
6	0.4	107	215	322	430	74	24	—	—	79	29	—	—	86	35	—	—	89	39	—	—	91	41	—	—	93	43	—	—
	.5	134	269	403	538	83	50	17	—	88	56	22	—	94	62	28	—	98	65	32	—	100	67	33	—	102	69	36	—
	.6	161	323	484	646	91	67	41	8	96	73	47	13	102	78	52	19	105	82	56	22	108	84	58	25	110	86	60	27
	.7	188	377	565	754	97	80	63	28	103	86	68	33	108	91	74	38	112	95	77	42	114	97	80	44	116	99	82	46
	.8	215	430	644	859	103	92	79	65	108	97	85	70	114	103	90	76	117	106	93	79	119	108	95	82	121	110	97	84
	.9	242	484	725	967	107	101	93	85	112	106	98	90	118	112	104	96	121	115	107	99	123	117	109	101	125	119	111	103
	1.0	269	538	806	1075	111	108	104	100	116	114	110	105	122	119	115	110	125	122	118	114	127	124	120	116	129	126	122	118
8	0.4	143	286	430	573	59	—	—	—	64	5	—	—	70	11	—	—	74	14	—	—	76	17	—	—	78	19	—	—
	.5	179	358	538	717	72	28	—	—	78	33	—	—	83	39	—	—	87	45	—	—	89	45	—	—	91	47	—	—
	.6	215	430	646	861	83	50	8	—	89	56	13	—	95	62	19	—	98	65	22	—	100	67	25	—	102	69	27	—
	.7	251	502	754	1005	91	69	28	18	97	75	33	24	102	80	38	29	105	84	42	32	108	86	44	35	110	88	46	36
	.8	286	573	859	1145	100	83	65	48	105	88	70	53	111	94	76	58	114	97	79	62	116	100	82	64	118	101	84	66
	.9	322	645	967	1290	105	96	85	73	110	101	90	78	116	106	96	84	119	110	99	87	121	112	101	89	123	114	103	91
	1.0	358	717	1075	1434	110	106	100	93	116	111	105	99	121	116	110	104	124	119	114	107	126	122	116	109	128	123	118	111

TABLE I.- Continued

CALCULATED SOUND-PRESSURE LEVELS OF THE FIRST FOUR ROTATIONAL-NOISE

HARMONICS FOR VARIOUS PROPELLER OPERATING CONDITIONS

[D = 12 feet]

B	M_t	Frequency, cps				Sound-pressure level, db																							
						I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4
		f_1	f_2	f_3	f_4	P_H = 1000				P_H = 2000				P_H = 4000				P_H = 6000				P_H = 8000				P_H = 10,000			
3	0.4	36	72	108	143	91	70	48	20	97	76	54	26	102	82	60	32	106	85	63	35	108	88	66	38	110	90	67	39
↓	.5	45	90	134	179	94	80	65	47	99	85	70	53	105	91	76	58	108	94	79	62	111	97	82	64	113	99	83	66
↓	.6	54	108	161	215	97	88	76	64	103	93	82	70	108	99	87	75	111	102	90	79	114	105	93	81	116	106	95	83
↓	.7	63	125	188	251	100	95	86	78	106	100	92	83	111	105	97	88	114	109	100	92	117	111	103	94	118	113	105	96
↓	.8	72	143	215	287	103	101	92	89	109	106	97	95	114	111	103	100	117	114	106	103	120	116	108	105	121	118	110	107
↓	.9	81	161	242	323	107	105	102	99	112	110	107	104	117	115	113	109	120	118	116	112	122	121	118	114	124	122	120	116
↓	1.0	90	179	269	358	109	109	108	106	114	114	113	111	119	119	118	116	122	122	121	119	124	124	123	122	126	126	125	123
4	0.4	48	96	143	191	82	38	20	—	88	44	26	—	93	50	32	8	97	53	35	11	99	56	38	13	101	58	39	15
↓	.5	60	119	179	239	88	54	47	25	93	59	53	30	99	65	58	36	102	68	67	39	105	71	64	42	106	74	66	43
↓	.6	72	143	215	288	94	80	64	47	100	86	70	53	105	91	75	58	108	95	78	62	111	97	81	64	113	99	83	66
↓	.7	84	167	251	335	99	88	77	67	104	94	83	72	110	99	88	77	113	103	92	81	115	105	94	83	117	107	96	85
↓	.8	96	191	287	382	103	97	89	90	108	102	96	86	113	108	100	91	117	111	103	94	119	113	105	96	121	115	107	98
↓	.9	108	215	323	430	104	103	99	93	109	108	104	98	114	113	109	104	118	116	111	107	120	119	114	109	122	120	117	111
↓	1.0	119	239	358	478	109	108	106	104	114	113	111	109	119	119	116	114	122	121	120	117	124	124	122	119	126	125	123	121
6	0.4	72	143	215	287	70	20	—	—	76	26	—	—	82	32	—	—	85	35	—	—	88	38	—	—	90	40	—	—
↓	.5	90	179	269	358	80	47	14	—	85	53	19	—	91	58	25	—	94	62	28	—	97	64	31	—	98	66	32	—
↓	.6	108	215	323	430	88	64	39	5	93	70	43	11	99	75	49	16	102	79	52	19	105	81	55	22	106	83	57	24
↓	.7	125	251	376	502	95	78	60	25	100	83	66	30	105	88	71	35	109	92	74	39	111	94	77	41	113	96	78	43
↓	.8	143	287	430	573	101	89	77	63	106	95	82	68	111	100	87	73	114	104	90	76	116	105	92	78	118	107	94	80
↓	.9	161	323	484	645	105	99	91	83	110	104	96	88	115	109	101	93	118	112	104	96	121	114	106	98	123	116	108	100
↓	1.0	179	358	538	717	109	106	102	98	114	111	107	103	119	116	112	108	122	120	116	111	124	122	118	113	126	124	119	115
8	0.4	96	191	287	382	55	—	—	—	61	—	—	—	67	8	—	—	70	11	—	—	73	13	—	—	75	16	—	—
↓	.5	119	239	358	478	69	25	—	—	74	30	—	—	80	36	—	—	84	39	—	—	86	42	—	—	88	43	—	—
↓	.6	143	287	430	573	80	48	5	—	86	53	11	—	91	58	16	—	95	62	19	—	97	64	22	—	99	66	24	—
↓	.7	167	335	502	669	88	67	25	15	94	72	30	21	99	77	35	26	103	87	39	29	105	83	41	32	107	85	43	33
↓	.8	191	382	573	764	97	80	63	45	102	86	68	50	108	91	73	55	111	94	76	59	113	96	78	61	115	98	80	63
↓	.9	215	430	645	860	103	93	83	70	108	98	88	76	113	104	93	81	116	107	96	84	119	109	98	86	120	111	100	88
↓	1.0	239	478	717	956	108	104	98	91	113	108	103	96	119	114	108	101	122	117	111	105	124	119	113	107	125	121	115	108

NACA

TABLE I.- Continued

CALCULATED SOUND-PRESSURE LEVELS OF THE FIRST FOUR ROTATIONAL-NOISE

HARMONICS FOR VARIOUS PROPELLER OPERATING CONDITIONS

[D = 16 feet]

B	M_t	Frequency, cps				Sound-pressure level, db							
						I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4
		f_1	f_2	f_3	f_4	P_H = 1000				P_H = 2000			
3	0.4	27	54	81	108	89	68	46	22	94	74	52	24
	.5	34	67	101	134	92	78	67	45	97	83	67	51
	.6	40	80	121	161	95	86	74	62	101	91	79	68
	.7	47	94	141	188	98	93	85	76	104	98	90	81
	.8	54	108	161	215	102	99	90	88	107	104	95	93
	.9	60	121	181	242	104	103	101	97	110	108	106	102
	1.0	67	134	202	269	108	108	107	105	112	112	111	110
4	0.4	36	72	108	143	80	36	18	—	86	42	24	—
	.5	45	90	134	179	86	51	45	22	91	57	51	28
	.6	54	108	161	215	92	78	62	46	97	84	68	51
	.7	63	125	188	251	97	86	76	65	102	92	81	70
	.8	72	143	215	287	101	95	88	79	106	101	93	84
	.9	81	161	242	323	103	101	97	92	108	106	102	97
	1.0	90	179	269	358	107	107	105	102	112	112	110	107
6	0.4	54	108	161	215	68	18	—	—	74	24	—	—
	.5	67	134	202	269	78	45	12	—	83	51	16	—
	.6	81	161	242	323	86	62	36	—	91	68	42	—
	.7	94	188	282	376	93	76	58	23	98	81	64	28
	.8	108	215	323	430	98	88	75	61	104	93	80	66
	.9	121	242	363	484	103	97	89	81	108	102	94	86
	1.0	134	269	403	538	108	105	101	96	112	110	106	101
8	0.4	72	143	215	287	53	—	—	—	59	—	—	—
	.5	90	179	269	358	67	22	—	—	72	28	—	—
	.6	108	215	323	430	78	46	4	—	84	51	8	—
	.7	125	251	376	502	86	65	23	14	92	70	28	19
	.8	143	287	430	573	95	78	61	43	101	84	66	48
	.9	161	323	484	645	101	92	81	69	106	97	86	74
	1.0	179	358	538	717	107	102	96	90	112	107	101	95

B	M_t	Sound-pressure level, db							
		I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4
		P_H = 4000				P_H = 6000			
3	0.4	100	80	58	30	103	83	61	33
	.5	103	89	73	56	106	92	76	59
	.6	106	97	85	73	109	100	88	77
	.7	109	103	95	86	112	107	98	90
	.8	112	109	101	98	115	111	104	101
	.9	115	113	112	107	118	116	113	110
	1.0	117	117	116	114	120	120	119	118
4	0.4	91	48	30	—	95	51	33	—
	.5	97	63	56	34	100	66	59	37
	.6	103	89	73	56	106	93	76	60
	.7	108	97	86	75	111	100	90	78
	.8	112	106	98	89	115	109	101	92
	.9	113	111	107	102	116	114	110	105
	1.0	117	117	115	112	120	120	118	115
6	0.4	80	30	—	—	83	33	—	—
	.5	89	56	22	—	92	59	25	—
	.6	97	73	47	14	100	77	50	17
	.7	103	86	69	33	107	90	72	37
	.8	109	98	85	71	111	101	88	74
	.9	113	107	100	91	116	110	102	94
	1.0	117	115	111	106	120	118	114	109
8	0.4	64	5	—	—	68	9	—	—
	.5	78	34	—	—	81	37	—	—
	.6	89	56	14	—	93	60	17	—
	.7	97	75	33	24	100	78	37	27
	.8	106	89	71	54	109	92	74	57
	.9	111	102	91	79	114	105	94	82
	1.0	117	112	106	100	120	115	109	103

B	M_t	Sound-pressure level, db							
		I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4
		P_H = 8000				P_H = 10,000			
3	0.4	106	85	63	36	108	87	65	37
	.5	109	94	78	62	110	96	80	64
	.6	112	102	91	79	114	104	92	81
	.7	114	109	101	92	116	111	102	93
	.8	118	114	106	103	119	116	108	105
	.9	121	119	116	112	122	120	118	114
	1.0	123	123	122	120	124	124	123	121
4	0.4	97	53	36	—	99	55	37	—
	.5	102	68	62	40	104	70	64	42
	.6	108	95	79	62	110	97	81	64
	.7	113	103	92	81	115	104	93	82
	.8	117	111	103	94	119	113	105	96
	.9	118	117	112	107	120	117	114	109
	1.0	122	122	120	117	124	124	122	119
6	0.4	85	36	—	—	87	38	—	—
	.5	94	62	28	—	96	64	30	—
	.6	102	79	53	19	104	81	54	21
	.7	109	92	74	39	111	93	76	41
	.8	114	103	90	77	116	105	92	78
	.9	119	112	104	96	120	119	106	98
	1.0	123	120	116	111	124	121	117	113
8	0.4	70	11	—	—	72	13	—	—
	.5	84	40	—	—	86	42	—	—
	.6	95	62	19	—	97	64	21	—
	.7	103	81	39	30	104	82	41	31
	.8	111	94	77	59	113	96	78	61
	.9	117	107	96	84	117	109	98	86
	1.0	122	117	111	105	124	119	113	106

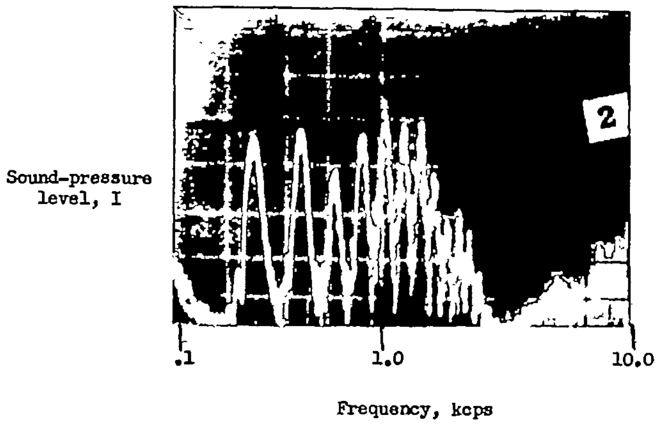
TABLE I.- Concluded

CALCULATED SOUND-PRESSURE LEVELS OF THE FIRST FOUR ROTATIONAL-NOISE

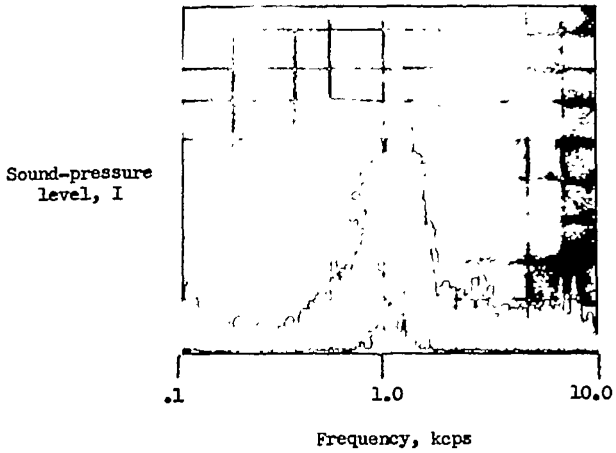
HARMONICS FOR VARIOUS PROPELLER OPERATING CONDITIONS

[D = 20 feet]

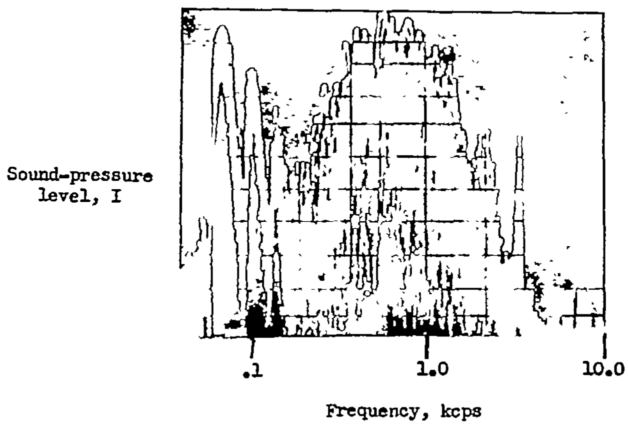
B	M_t	Frequency, cps				Sound-pressure level, db																							
						I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4
		f_1	f_2	f_3	f_4	P_H = 1000				P_H = 2000				P_H = 4000				P_H = 6000				P_H = 8000				P_H = 10,000			
3	0.4	22	43	65	86	87	67	42	17	92	72	50	22	98	78	56	28	102	81	59	31	104	84	62	34	106	85	64	36
	.5	27	54	81	108	90	76	60	44	96	82	65	49	101	87	71	55	104	90	74	58	107	93	76	60	109	95	78	62
	.6	32	64	97	129	94	85	73	61	100	90	78	66	104	95	84	72	108	98	86	75	110	101	89	77	112	103	91	79
	.7	38	75	113	150	97	91	83	74	102	97	88	73	108	102	94	85	111	105	97	88	113	107	100	90	115	109	101	92
	.8	43	86	129	172	101	97	89	86	106	102	94	91	111	108	99	96	114	111	102	100	116	113	104	102	118	115	106	103
	.9	48	97	145	194	104	102	99	96	109	107	104	95	114	112	109	106	117	115	112	109	119	117	115	111	121	119	116	113
	1.0	54	108	161	215	106	106	105	104	111	111	110	108	116	116	115	113	119	119	118	116	121	121	120	118	123	123	122	120
4	.4	29	57	86	115	78	35	—	—	84	40	22	—	89	46	28	—	93	49	31	7	95	52	13	10	97	55	35	11
	.5	36	72	108	143	84	50	43	21	89	55	49	27	95	61	55	32	98	64	58	36	100	66	60	38	102	68	62	40
	.6	43	86	129	172	91	77	61	44	96	82	66	49	101	88	72	55	104	91	75	58	107	93	78	60	109	95	79	62
	.7	50	100	150	201	96	85	74	64	101	90	79	69	106	96	85	74	109	99	88	77	111	101	90	79	113	103	92	81
	.8	57	115	172	229	100	94	86	77	105	99	91	82	110	104	96	88	113	107	99	91	115	110	102	93	117	111	103	95
	.9	65	129	194	258	101	100	96	90	106	105	101	95	111	110	106	100	114	113	109	103	116	115	111	106	118	117	113	108
	1.0	72	143	215	287	106	106	104	101	111	111	108	106	116	116	113	111	119	118	116	114	121	120	118	116	122	122	120	117
6	0.4	43	86	129	172	66	17	—	—	72	22	—	—	78	28	—	—	81	31	—	—	84	33	—	—	85	35	—	—
	.5	54	108	161	215	76	43	10	—	82	49	15	—	87	55	21	—	90	58	24	—	93	60	27	—	95	62	28	—
	.6	64	129	193	258	85	61	35	4	90	66	40	7	95	72	45	12	98	75	49	16	101	77	51	18	103	79	53	20
	.7	75	150	226	301	91	74	57	22	96	78	62	27	102	85	68	32	105	88	70	35	107	90	73	37	109	92	75	39
	.8	86	172	258	344	97	86	73	60	102	85	68	32	108	96	83	64	111	100	87	73	113	102	89	75	115	103	91	77
	.9	97	194	290	387	102	96	88	80	107	100	93	85	112	106	98	90	115	109	101	93	117	111	103	94	119	113	105	97
	1.0	108	215	323	430	106	104	100	95	111	108	104	94	116	113	109	105	119	116	112	108	121	118	114	110	123	120	116	111
8	0.4	57	115	172	229	51	—	—	—	57	—	—	—	63	5	—	—	66	7	—	—	69	9	—	—	70	11	—	—
	.5	72	143	215	287	65	21	—	—	71	27	—	—	76	32	—	—	79	15	—	—	82	37	—	—	84	40	—	—
	.6	86	172	258	344	77	44	4	—	82	49	7	—	88	55	12	—	91	58	16	—	93	60	18	—	95	62	20	—
	.7	100	200	301	401	85	64	22	12	90	49	27	17	96	74	32	22	99	77	35	26	101	79	37	28	103	81	39	30
	.8	115	229	344	459	94	77	60	42	99	82	65	47	104	88	70	52	107	91	73	55	110	93	75	57	111	94	77	59
	.9	129	258	387	516	100	90	80	68	105	95	85	73	110	100	90	58	113	103	92	81	115	106	95	83	117	107	97	85
	1.0	143	287	430	573	106	101	95	89	111	106	99	93	116	111	105	98	118	114	108	101	120	116	110	103	122	117	111	105



(a) Rotational noise from high-speed propeller.

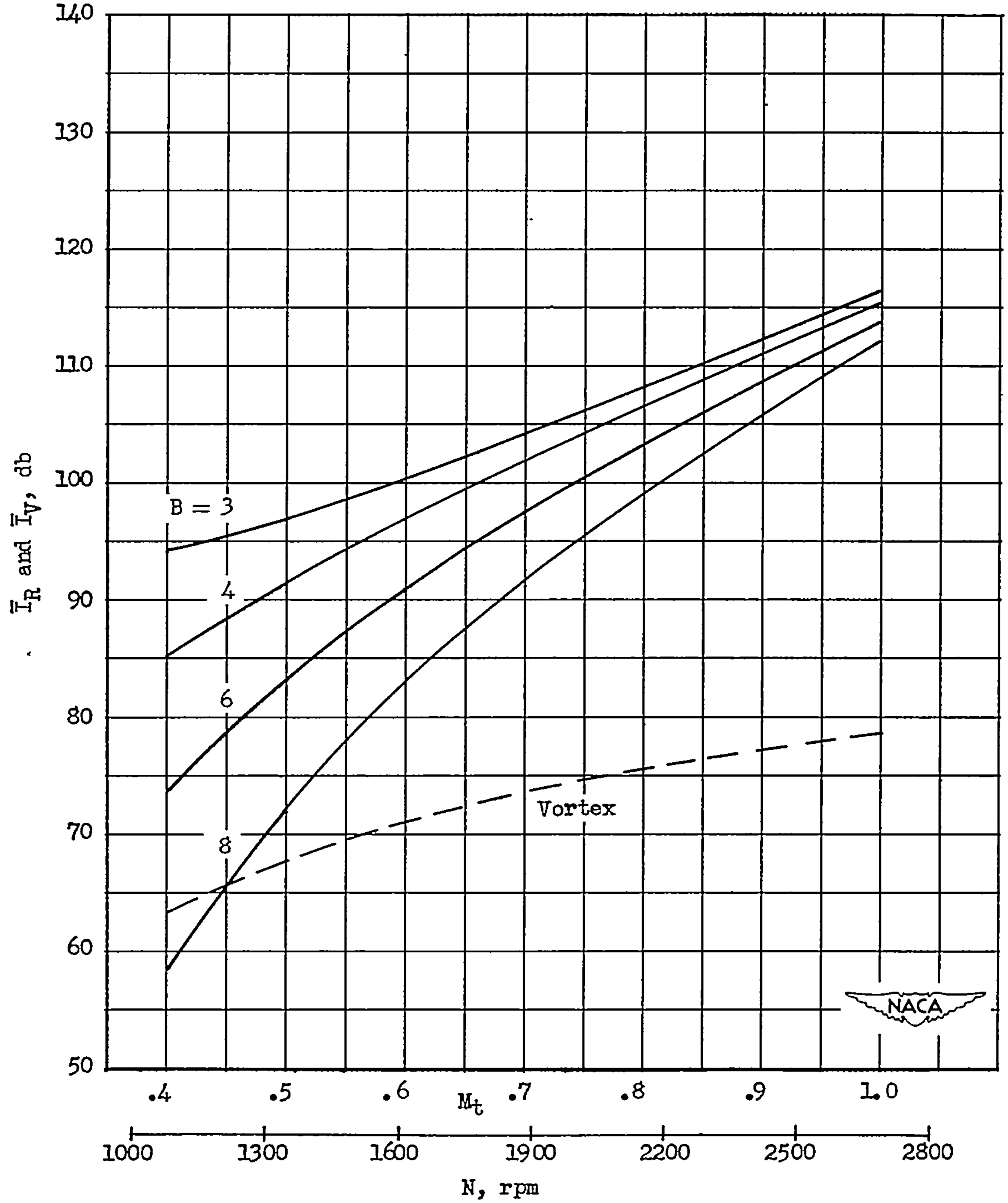


(b) Vortex noise from rotating rods.



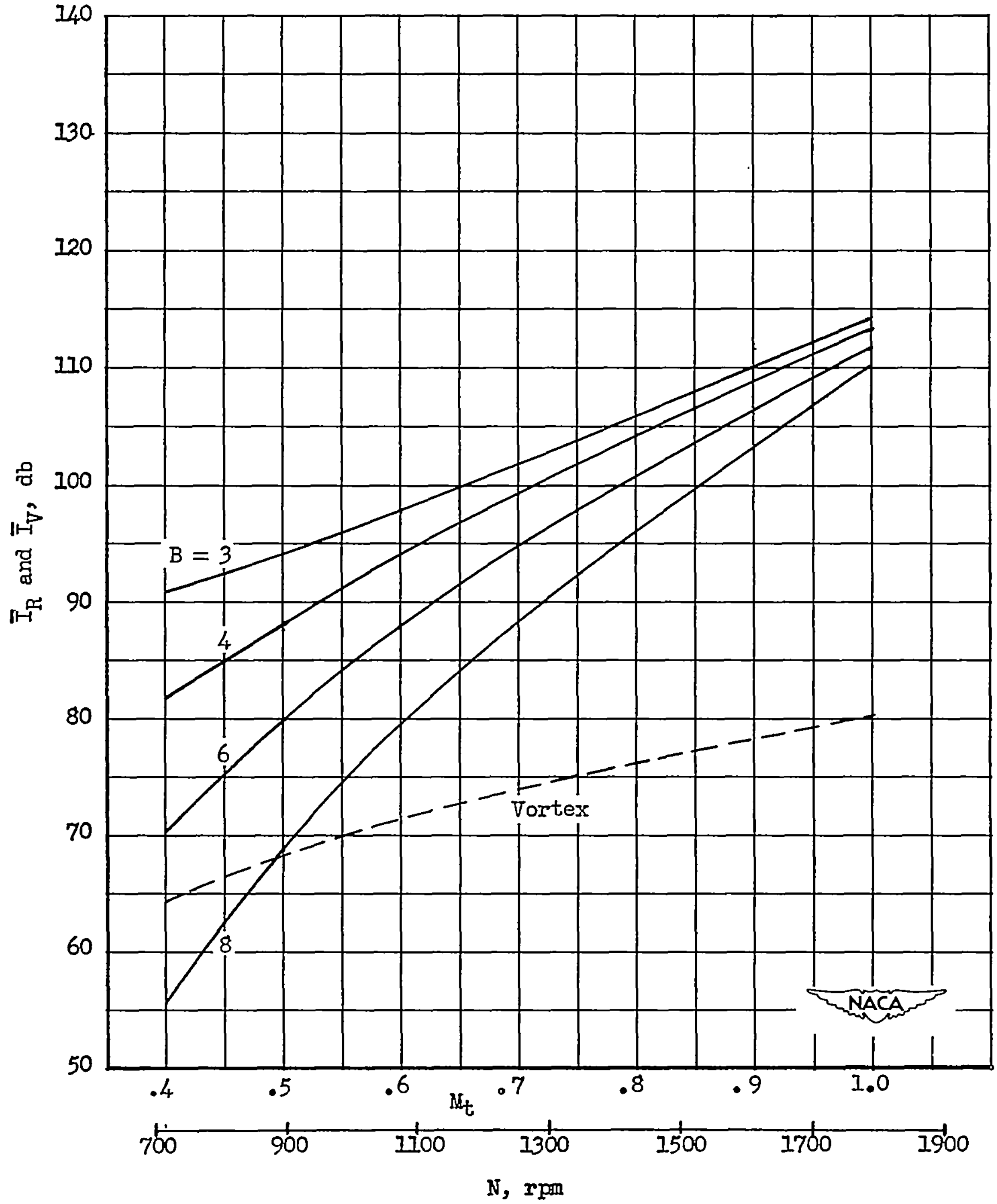
(c) Composite spectrum of rotational and vortex noise.

Figure 1.- Spectrums of components of propeller noise.



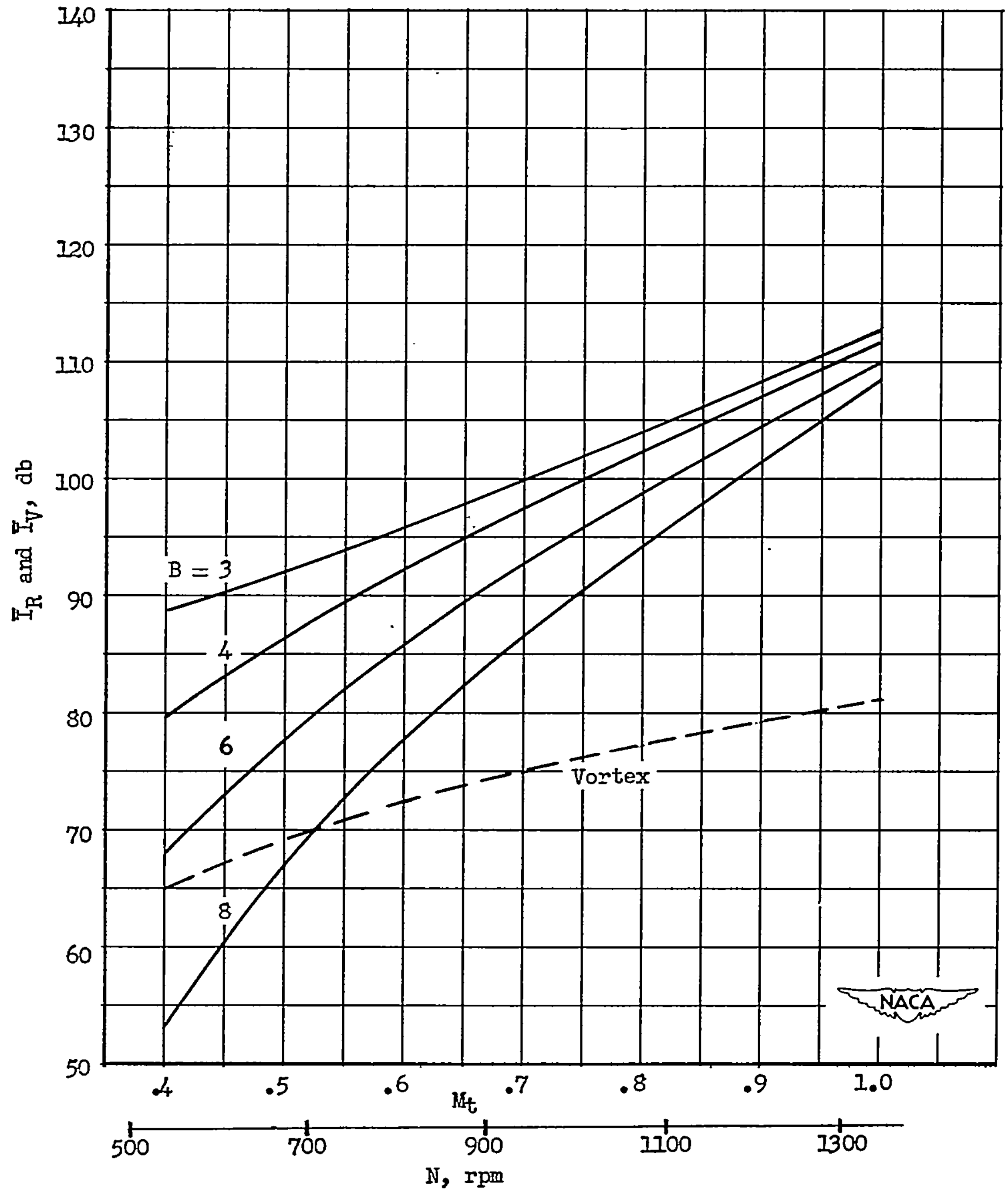
(a) D = 8 feet.

Figure 2.- Propeller sound-pressure levels as functions of tip Mach number and rotational speed for various numbers of blades. P_H = 1,000 horsepower; s = 300 feet.



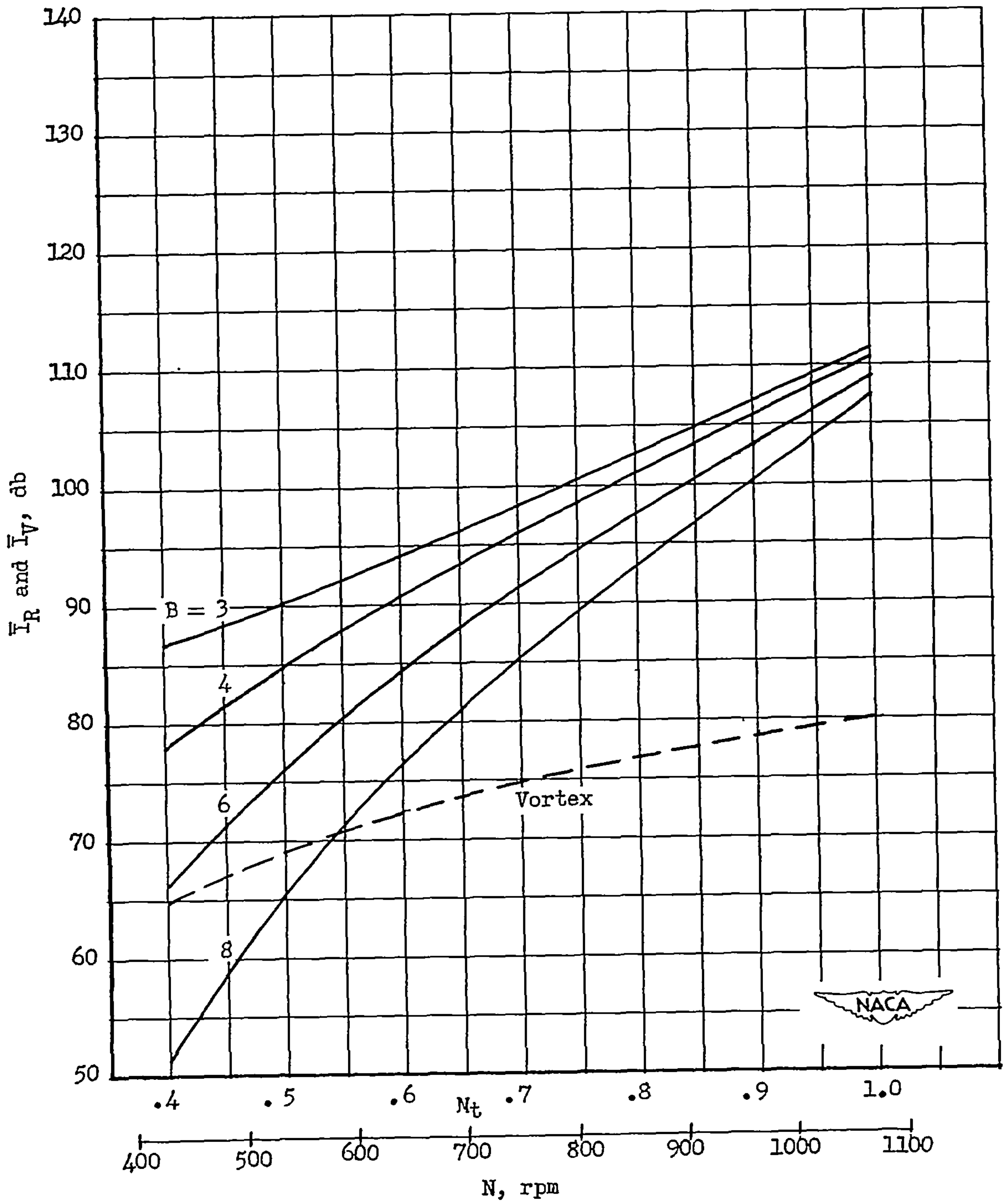
(b) D = 12 feet.

Figure 2.- Continued.



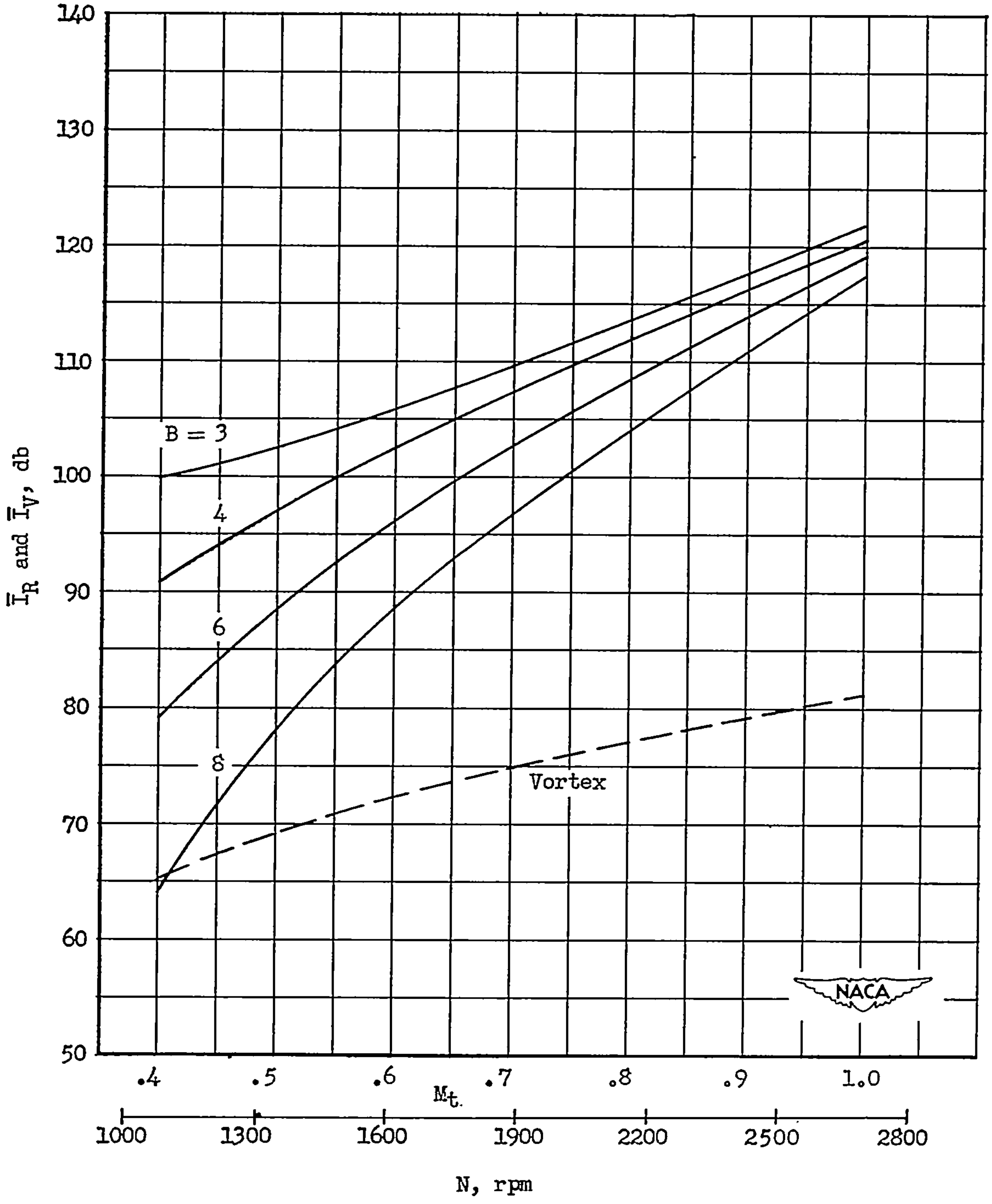
(c) D = 16 feet.

Figure 2.- Continued.



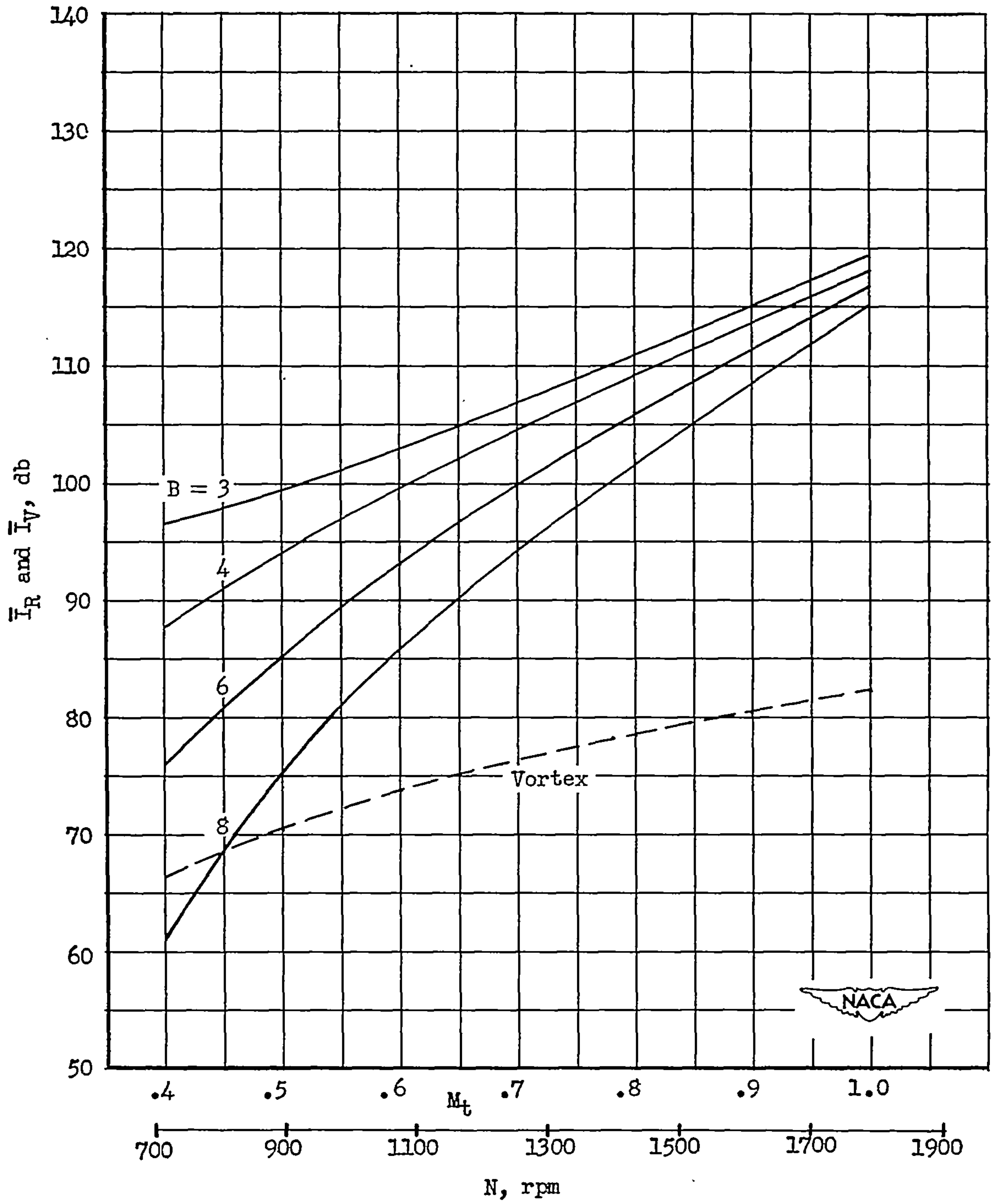
(d) D = 20 feet.

Figure 2.- Concluded.



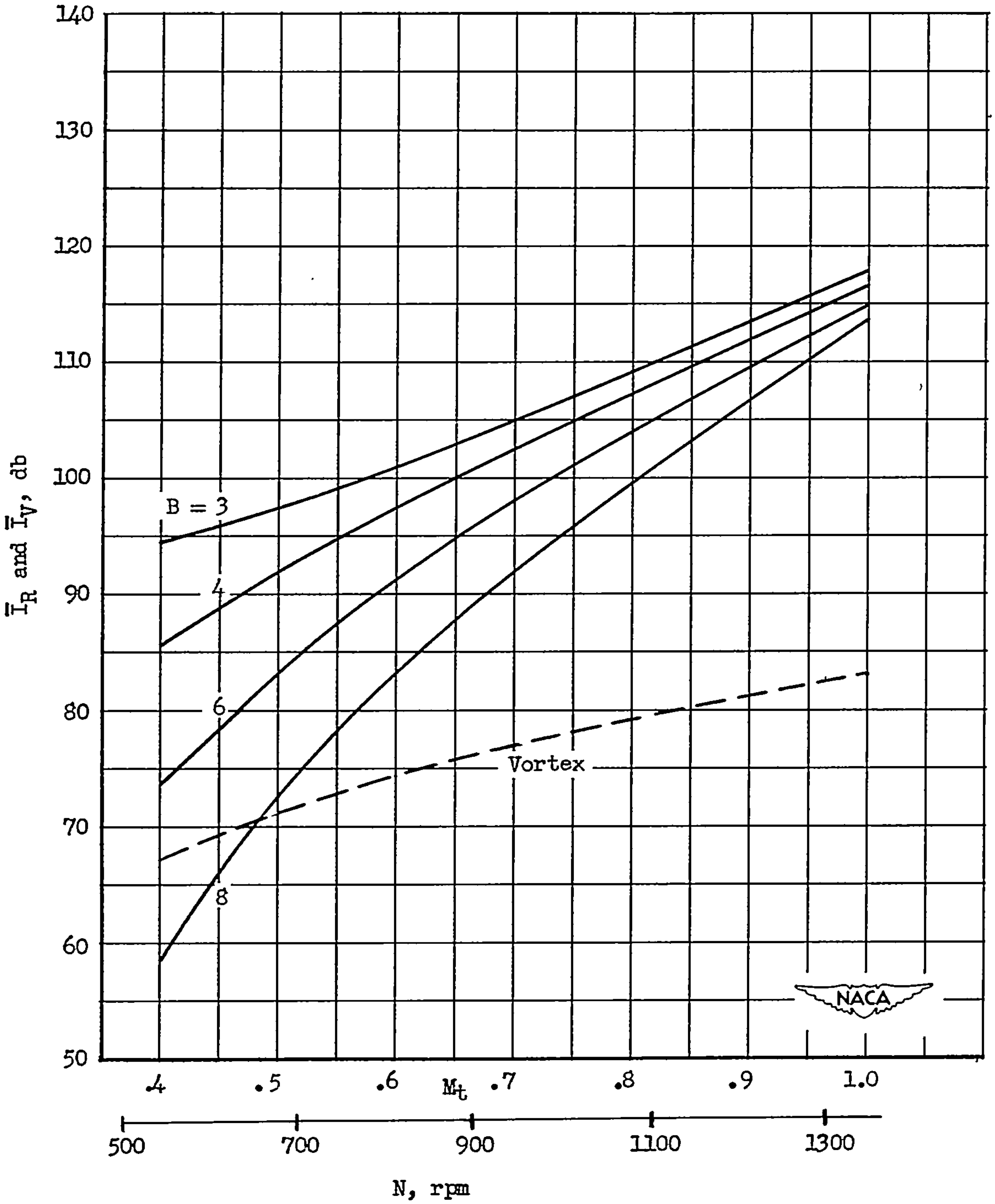
(a) D = 8 feet.

Figure 3.- Propeller sound-pressure levels as functions of tip Mach number and rotational speed for various numbers of blades. P_H = 2,000 horsepower; s = 300 feet.



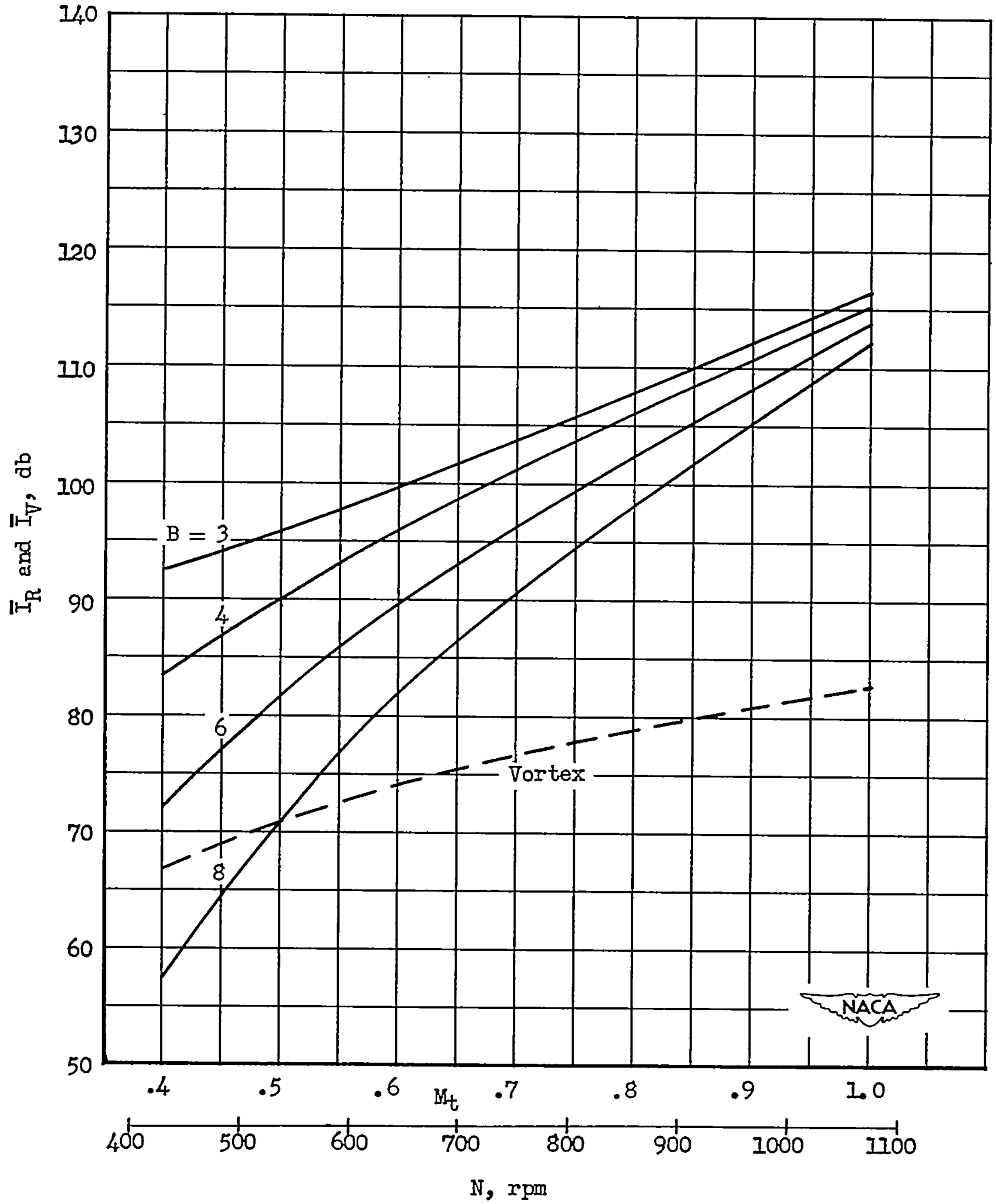
(b) D = 12 feet.

Figure 3.- Continued.



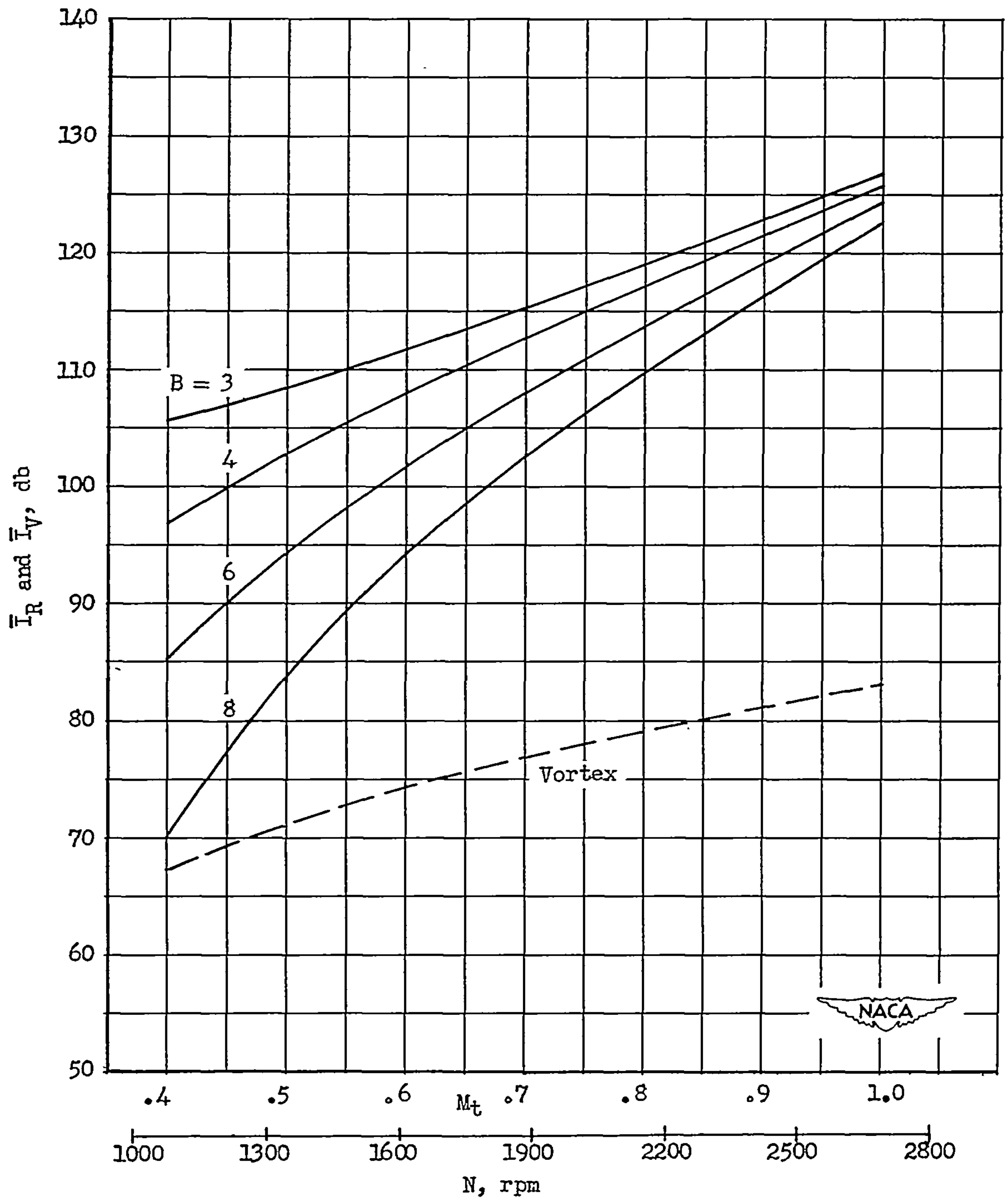
(c) D = 16 feet.

Figure 3.- Continued.



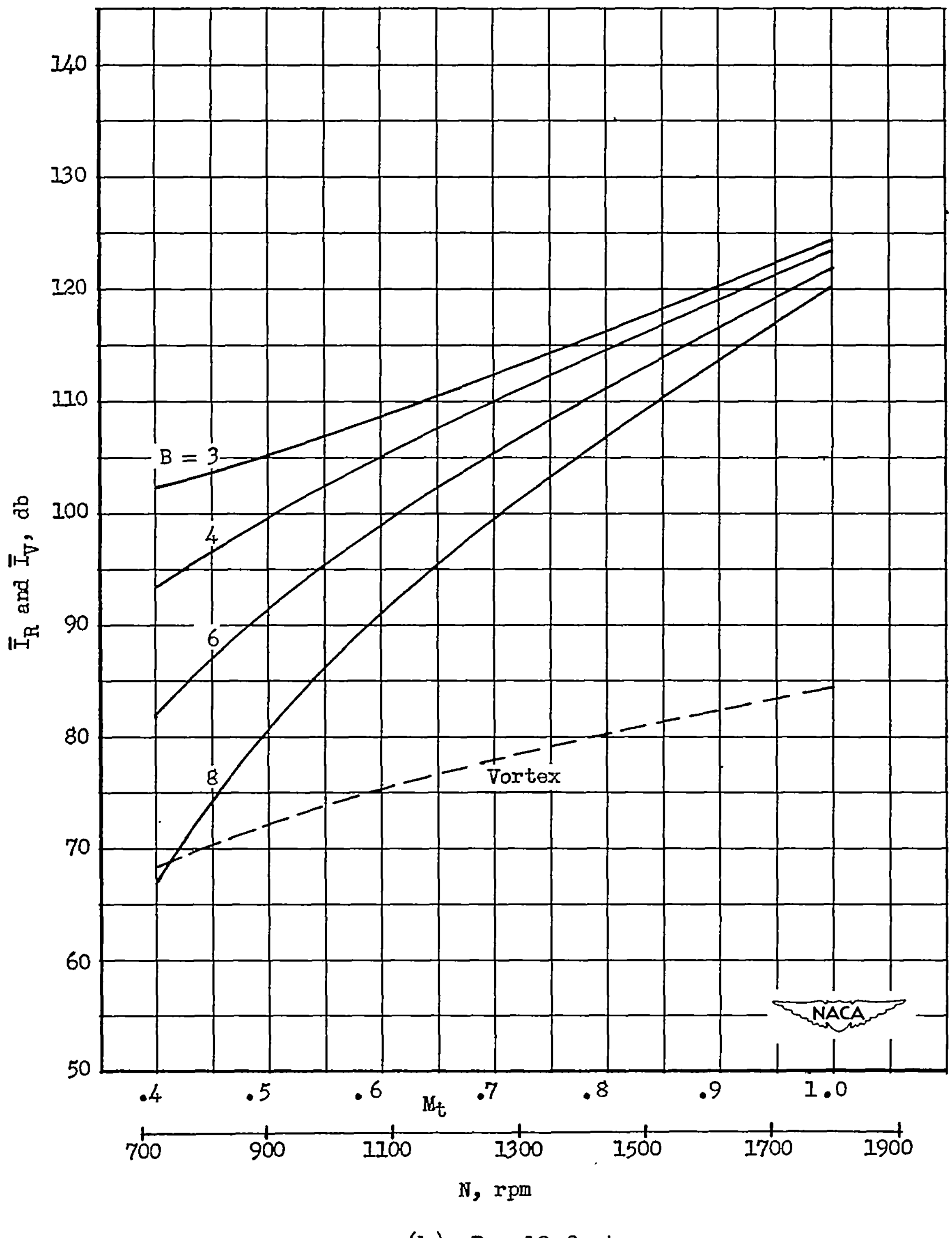
(d) D = 20 feet.

Figure 3.- Concluded.



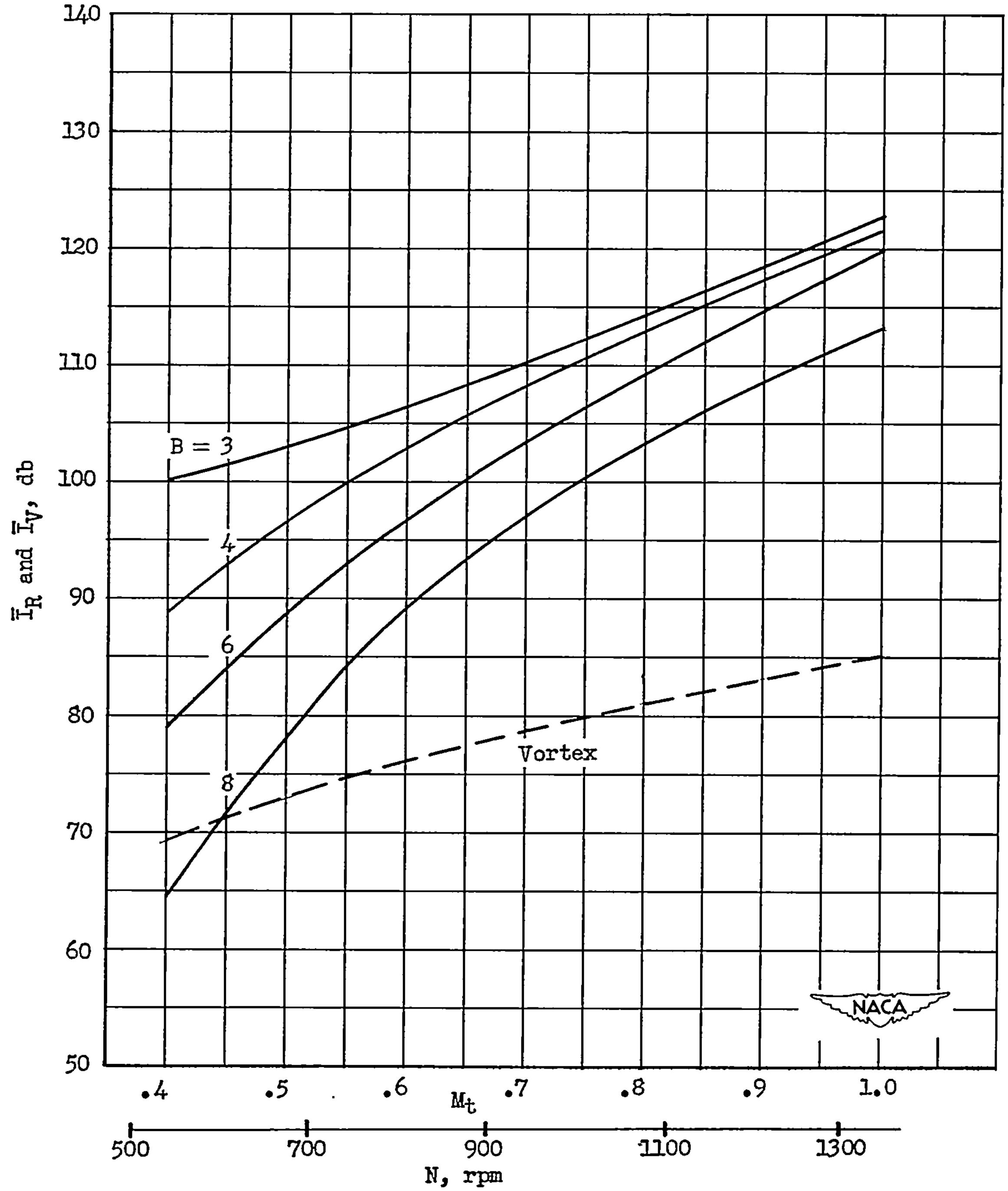
(a) D = 8 feet.

Figure 4.- Propeller sound-pressue levels as functions of tip Mach number and rotational speed for various numbers of blades. P_H = 4,000 horsepower; s = 300 feet.



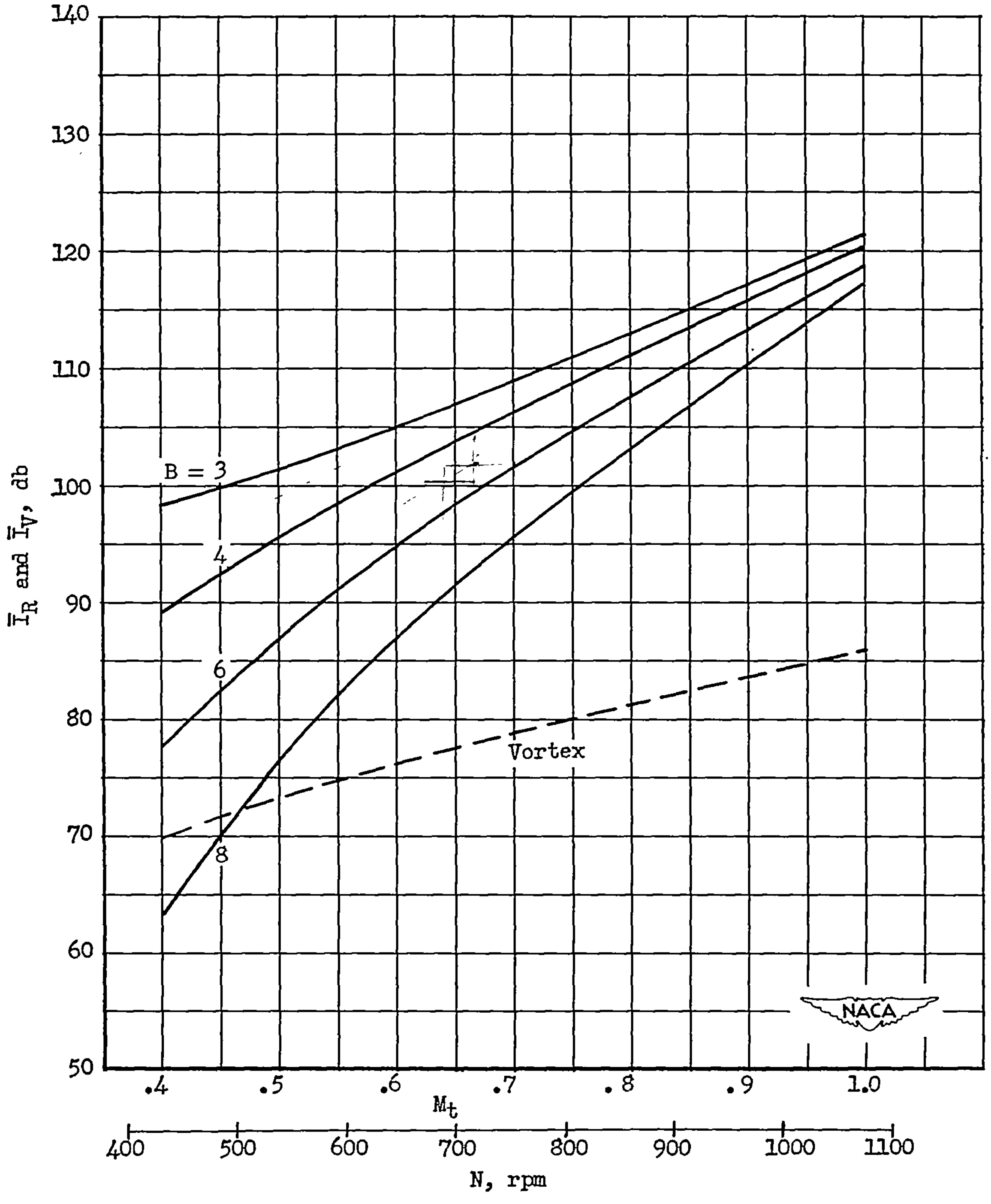
(b) D = 12 feet.

Figure 4.- Continued.



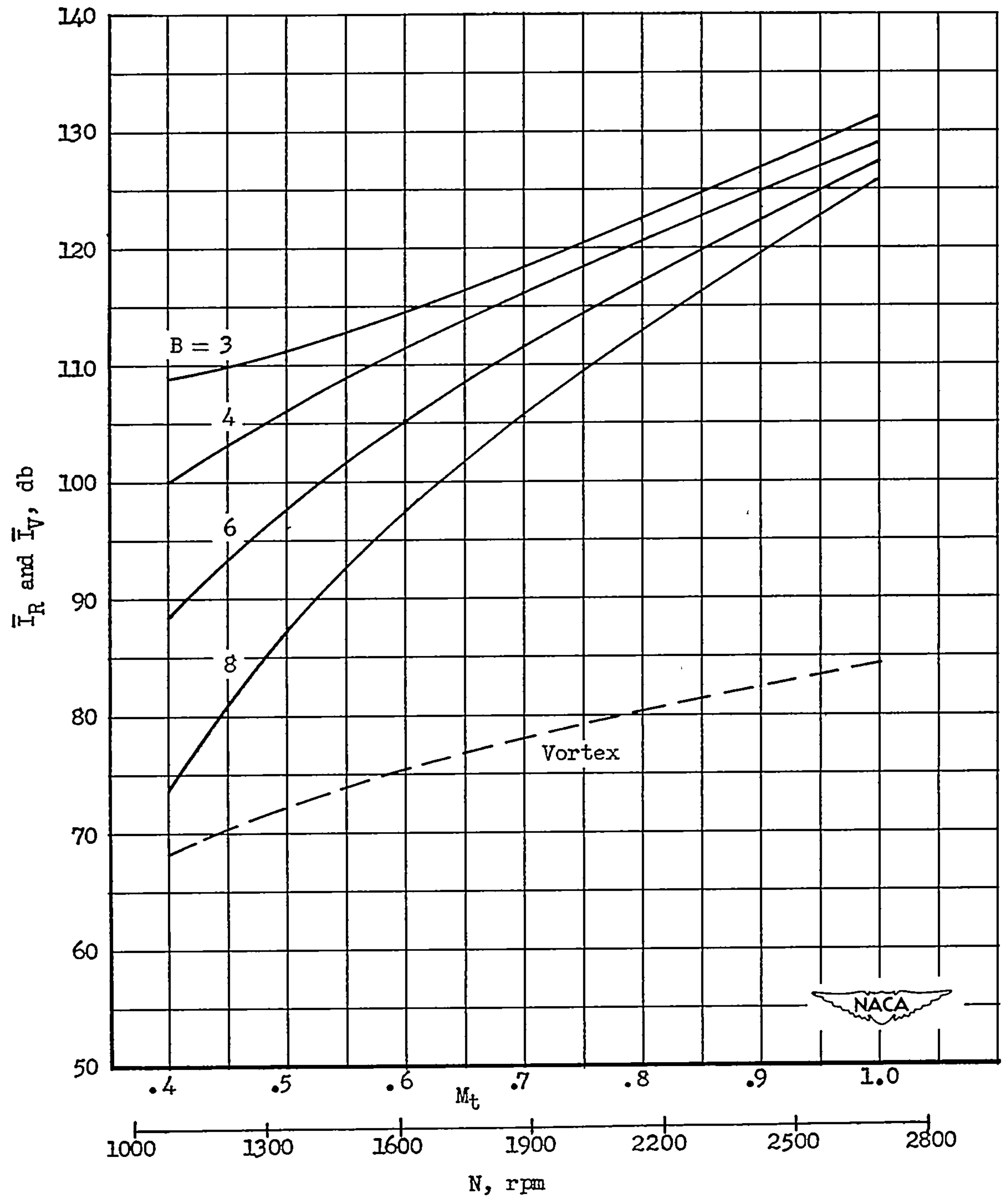
(c) D = 16 feet.

Figure 4.- Continued.



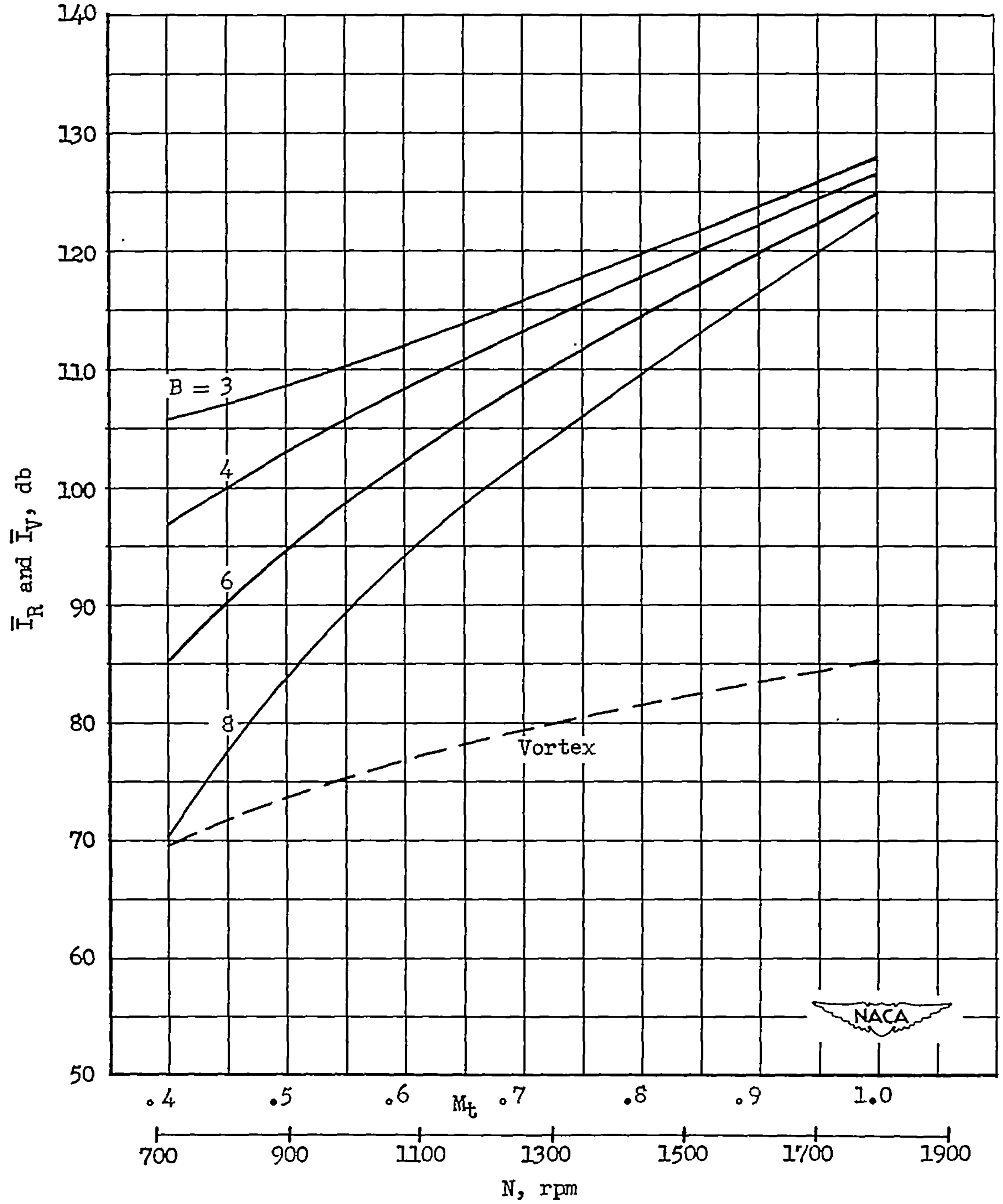
(d) D = 20 feet.

Figure 4.- Concluded.



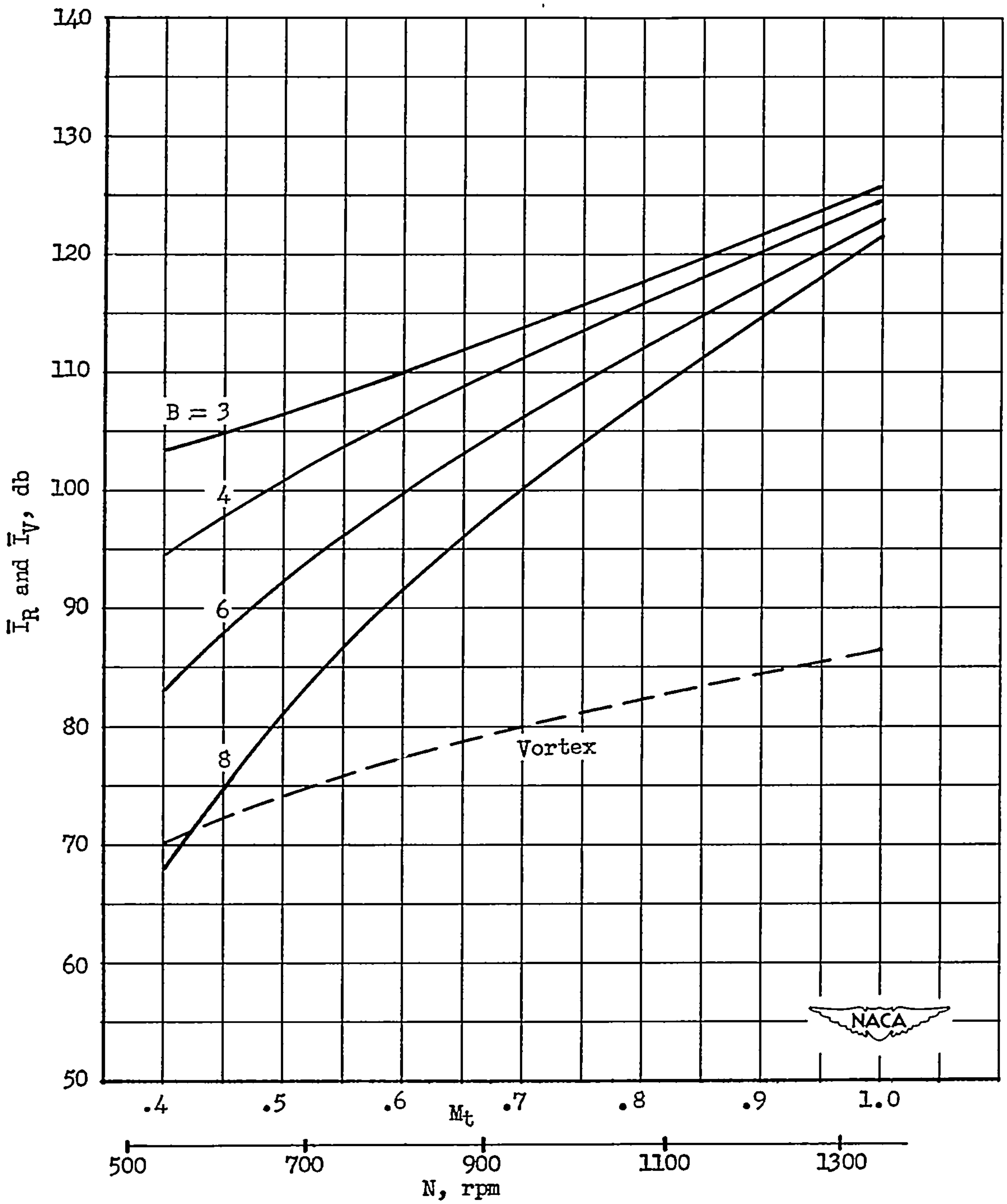
(a) D = 8 feet.

Figure 5.- Propeller sound-pressure levels as functions of tip Mach number and rotational speed for various numbers of blades. P_H = 6,000 horsepower; s = 300 feet.



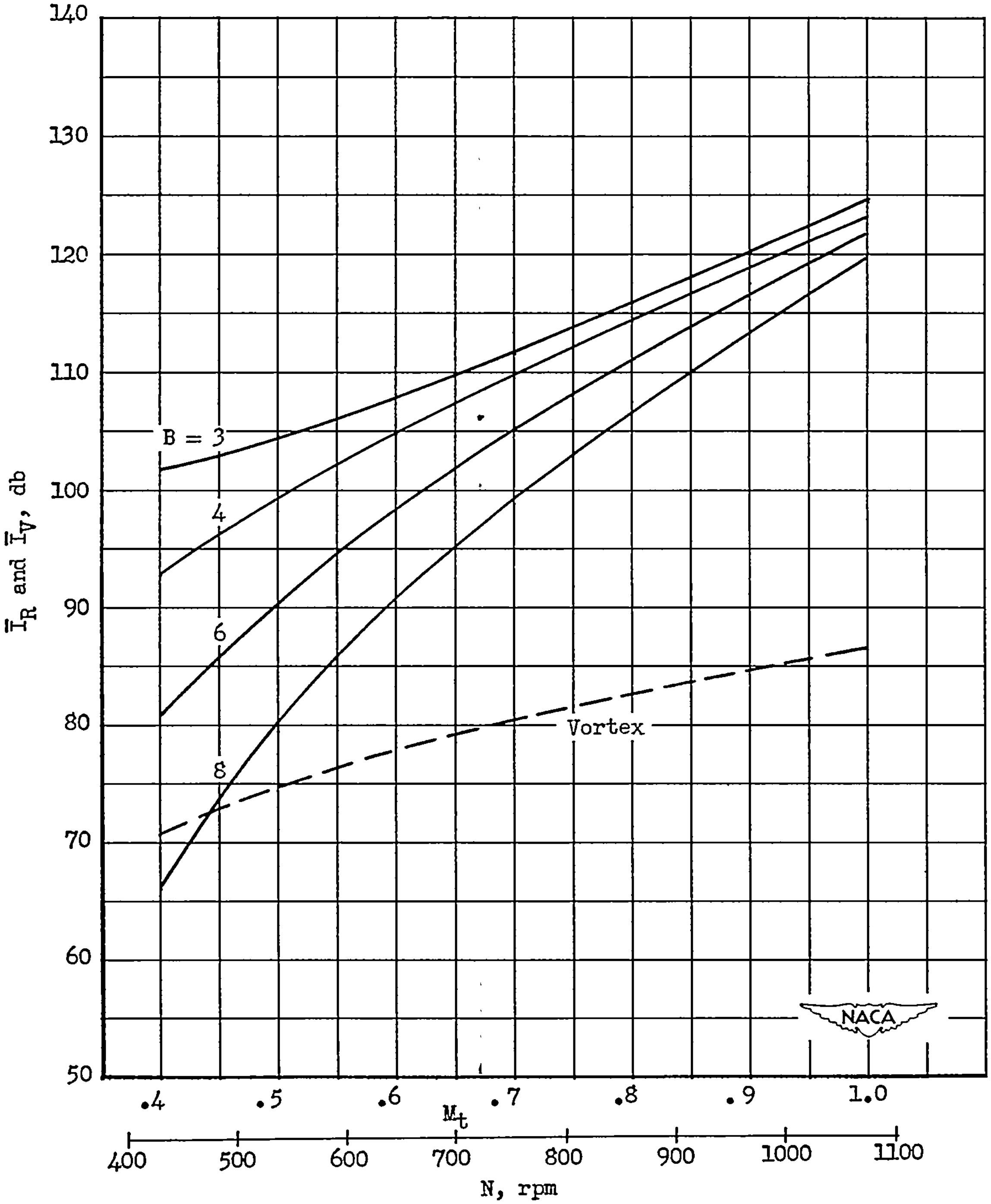
(b) D = 12 feet.

Figure 5.- Continued.



(c) D = 16 feet.

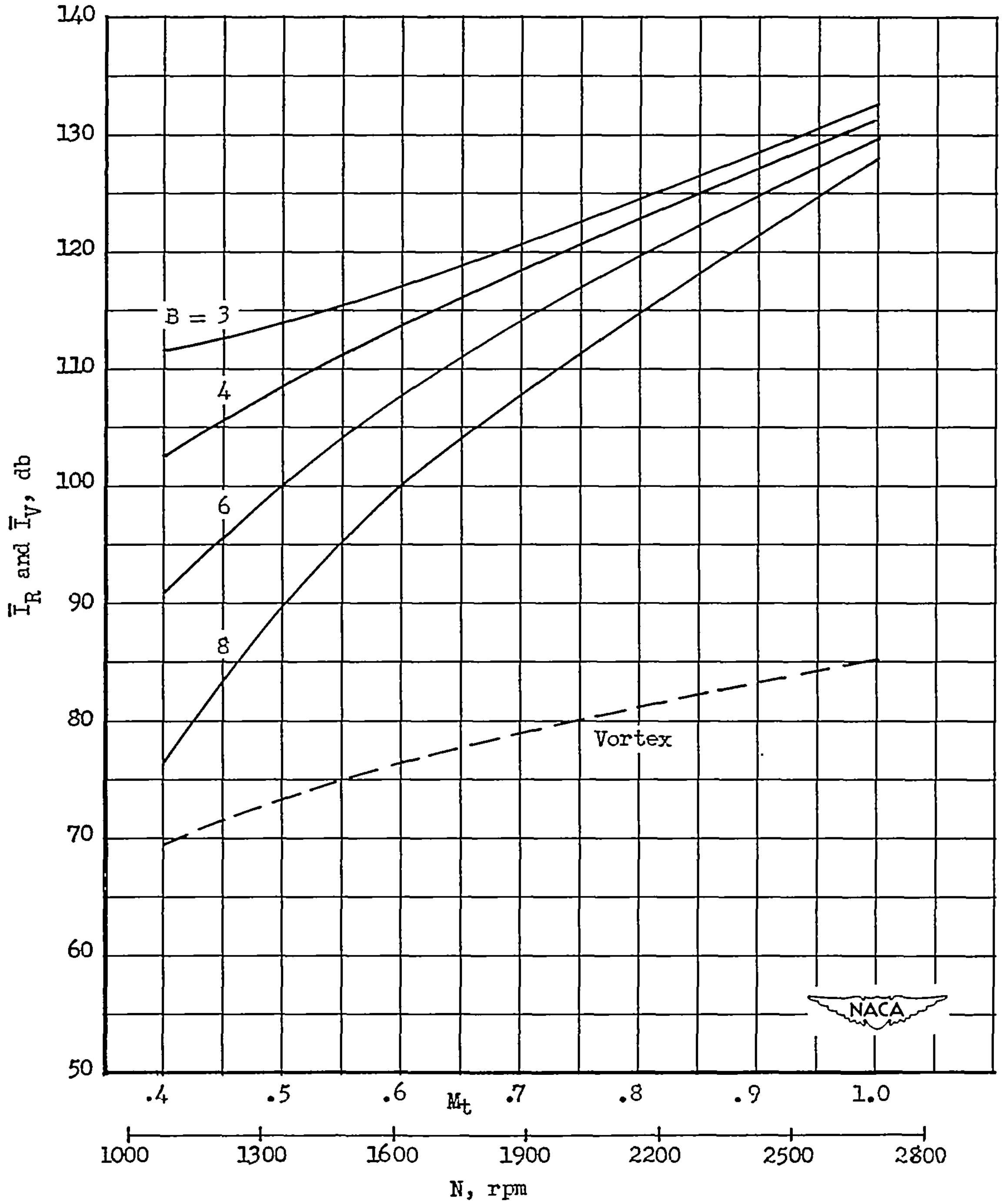
Figure 5.- Continued.



(d) D = 20 feet.

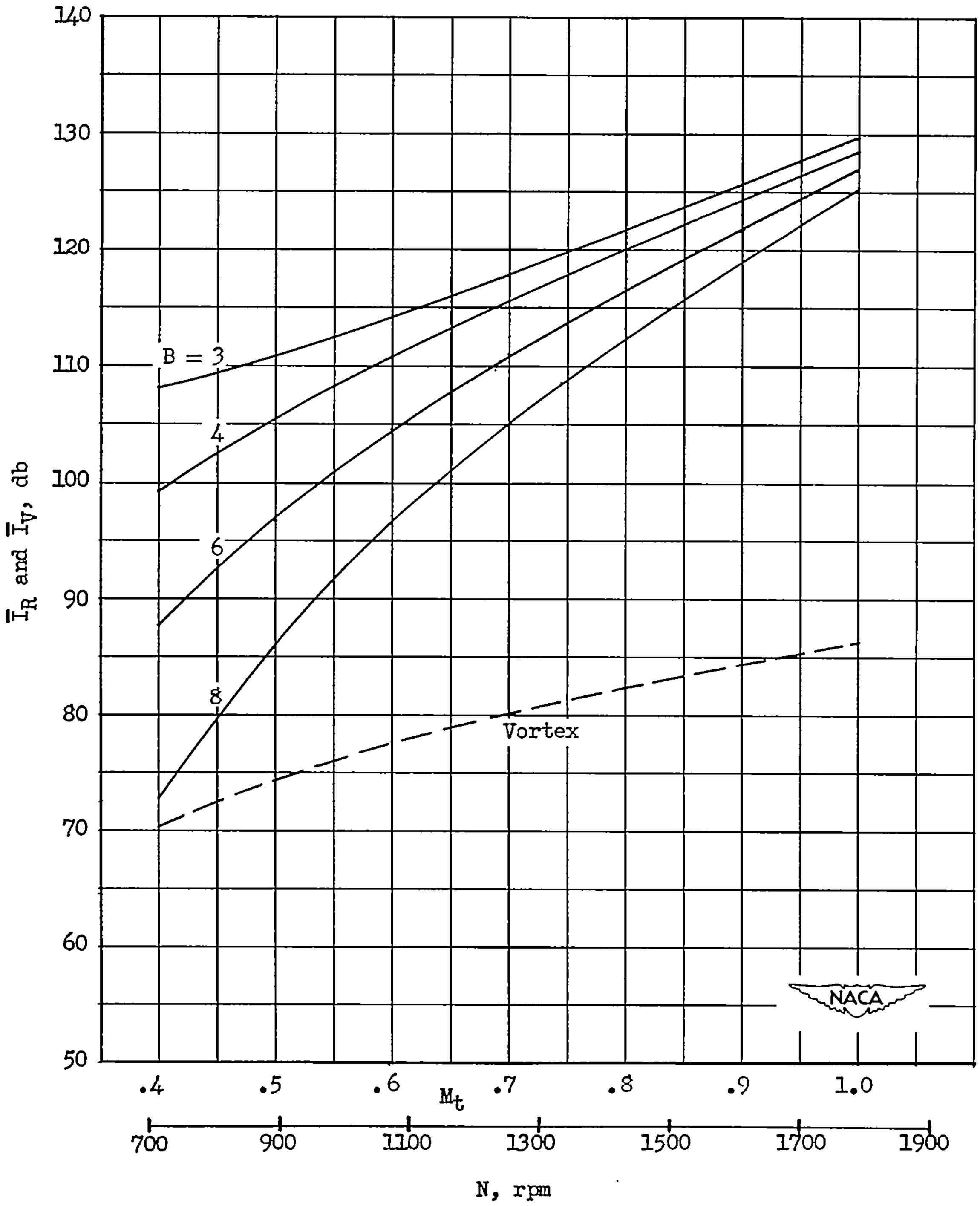
Figure 5.- Concluded.

6000 hp
300 ft.



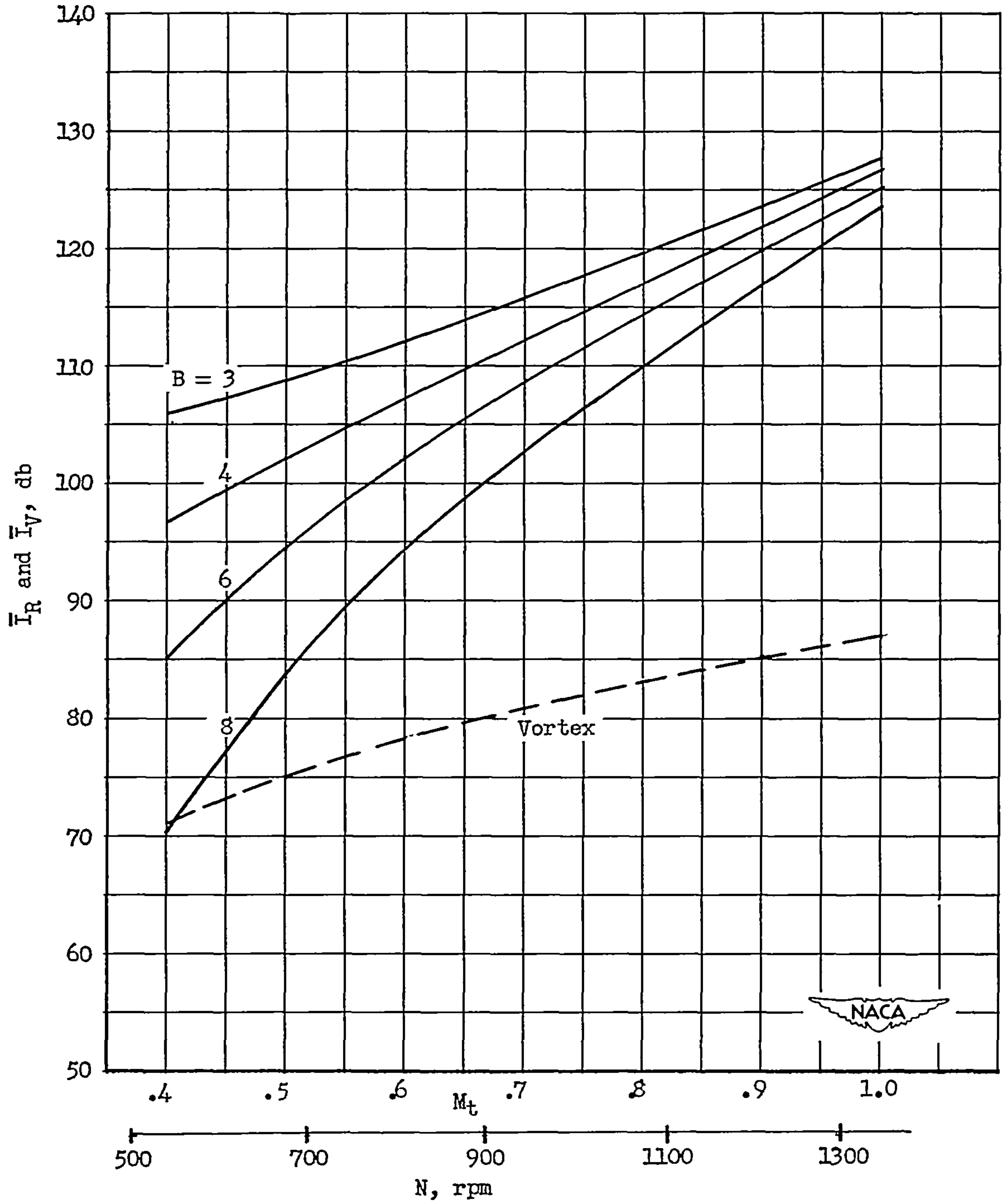
(a) D = 8 feet.

Figure 6.- Propeller sound-pressure levels as functions of tip Mach number and rotational speed for various numbers of blades. P_H = 8,000 horsepower; s = 300 feet.



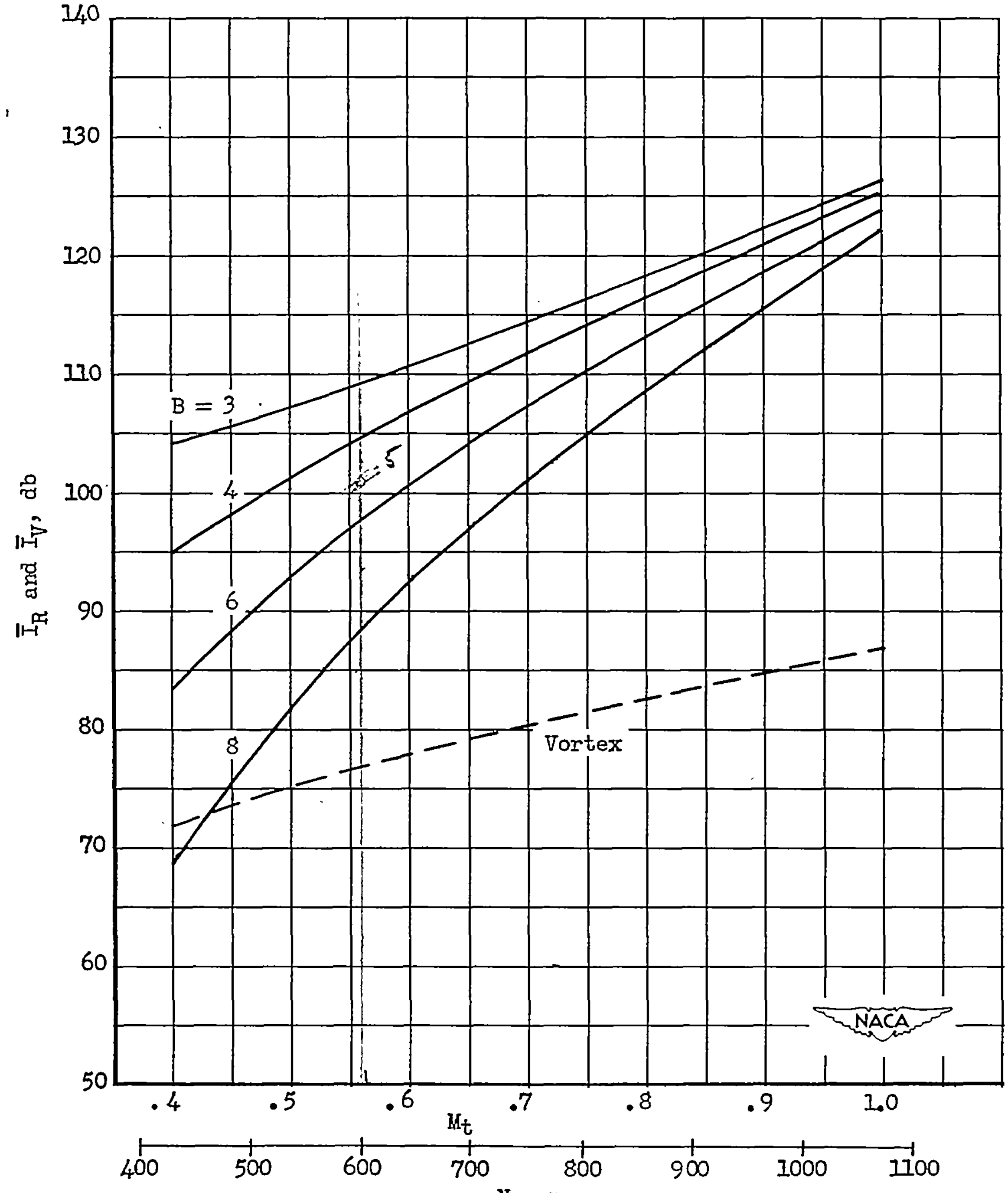
(b) D = 12 feet.

Figure 6.- Continued.



(c) D = 16 feet.

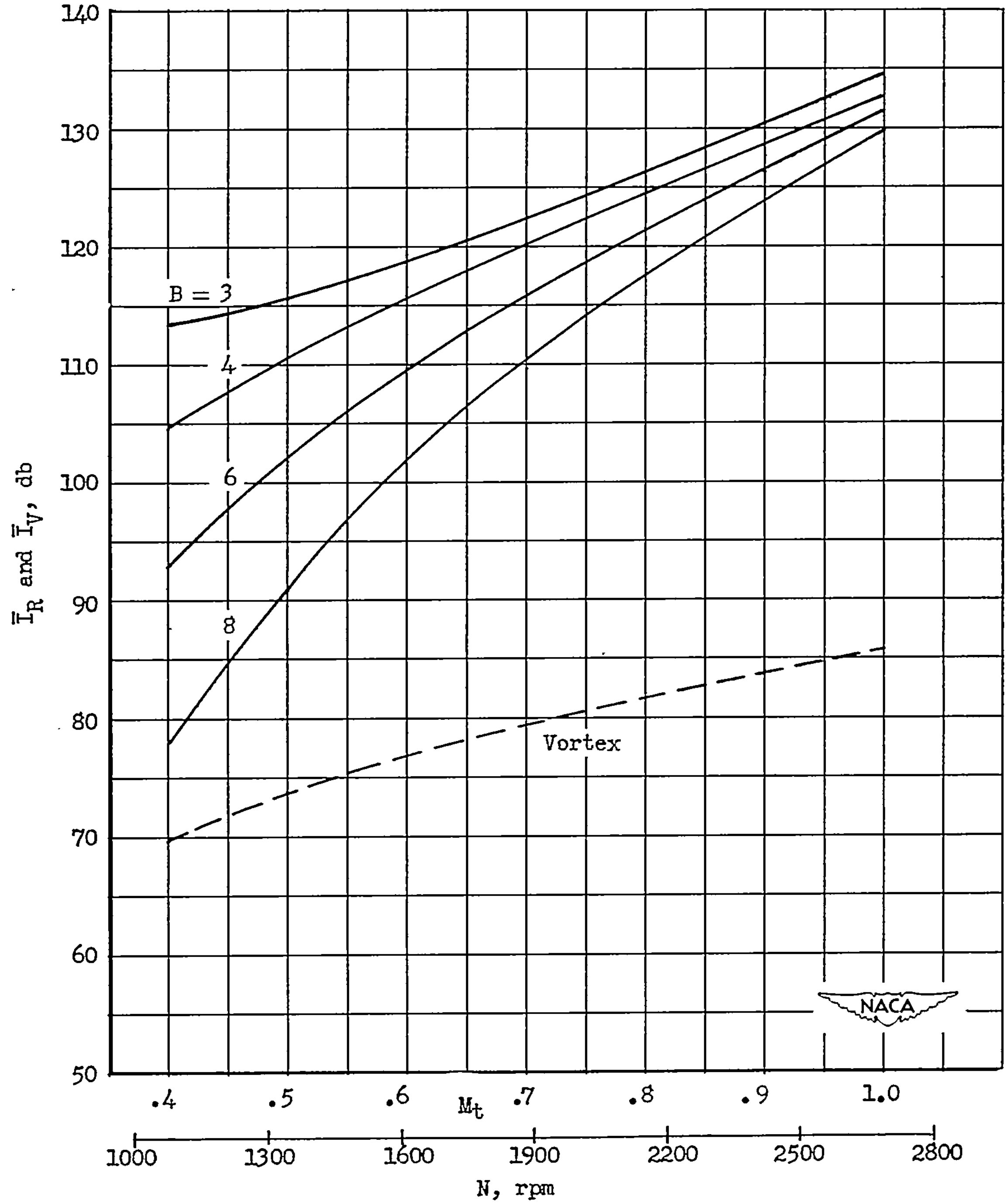
Figure 6.- Continued.



(d) D = 20 feet.

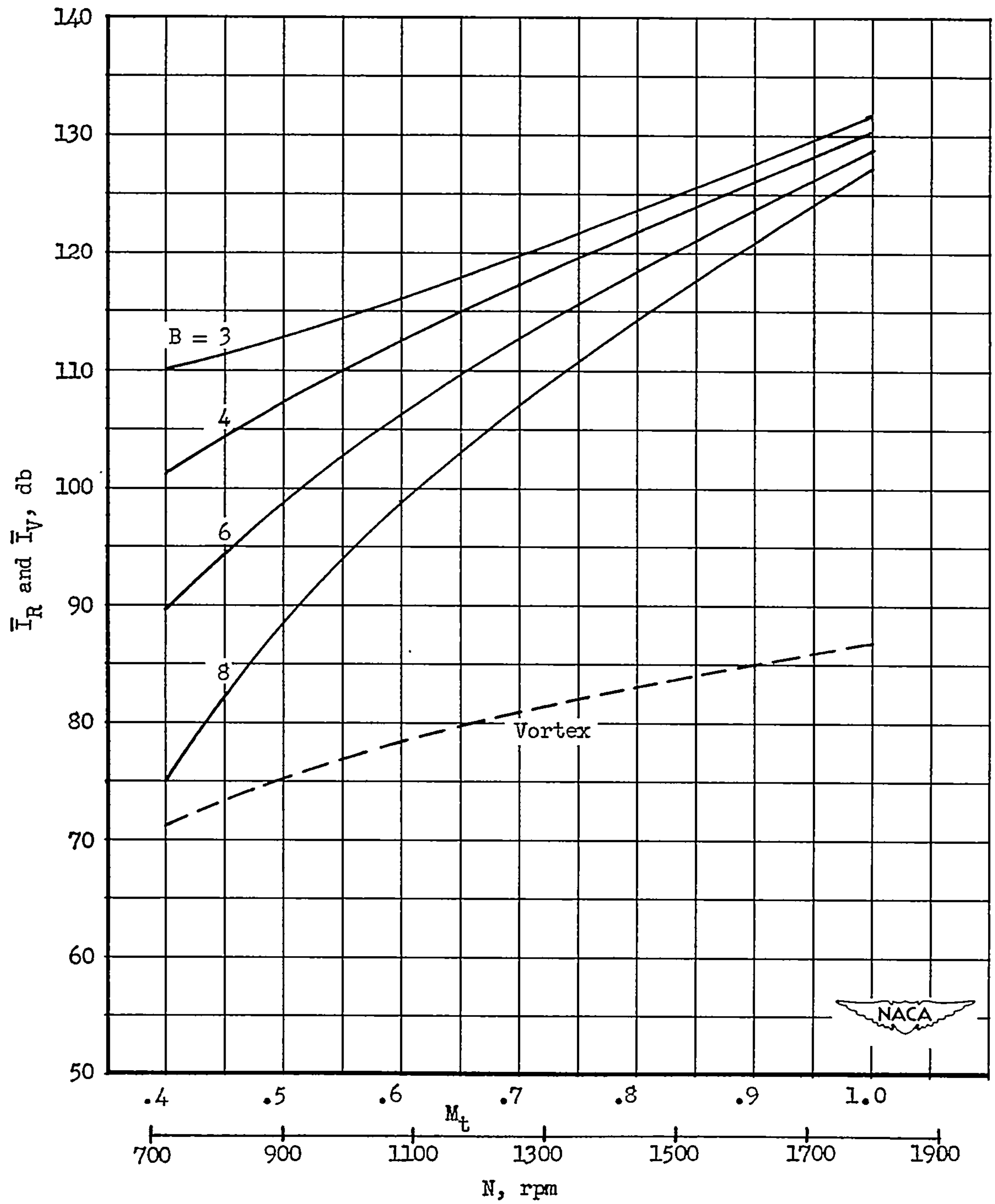
8000 hp

Figure 6.- Concluded.



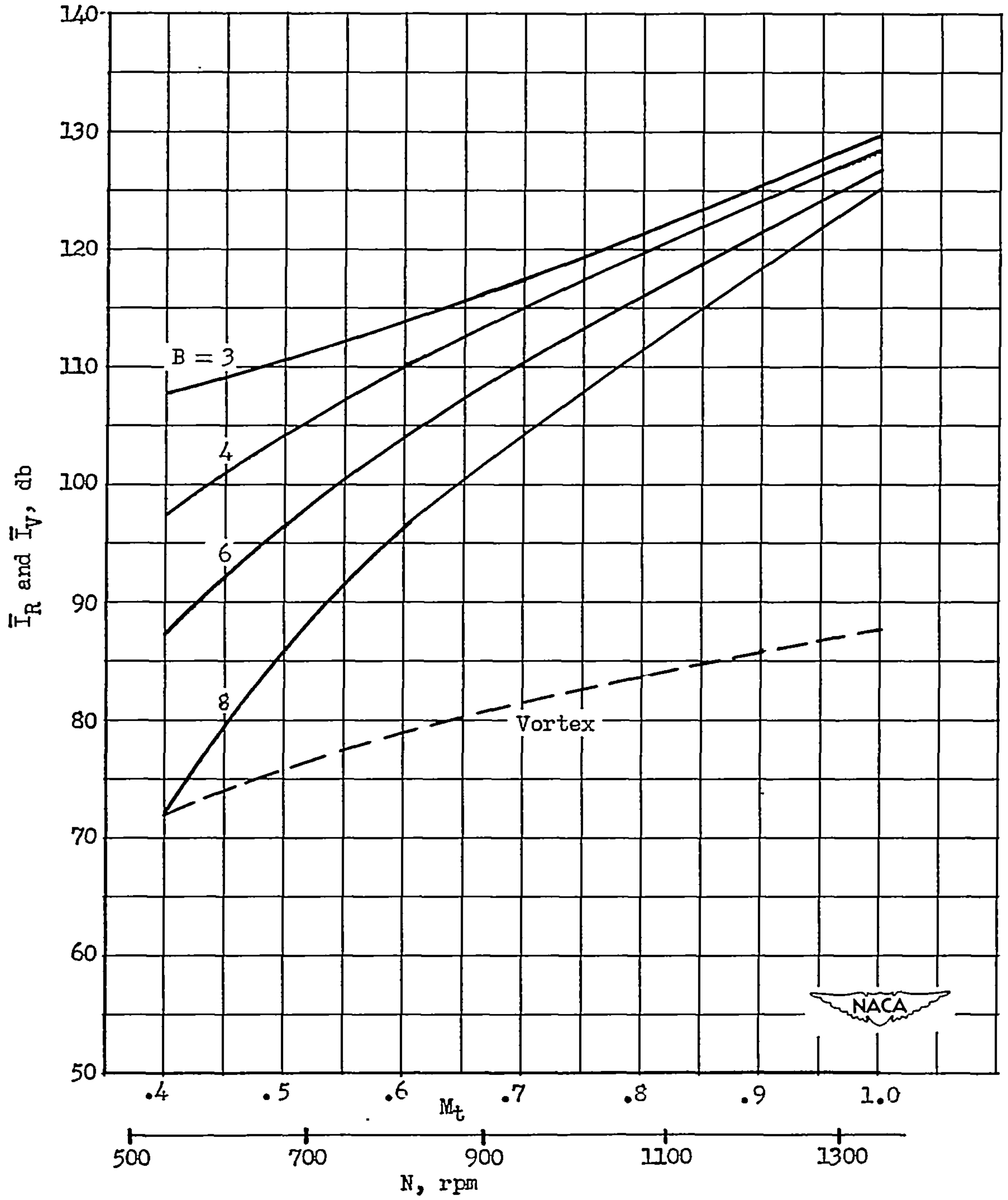
(a) D = 8 feet.

Figure 7.- Propeller sound-pressure levels as functions of tip Mach number and rotational speed for various numbers of blades. P_H = 10,000 horsepower; s = 300 feet.



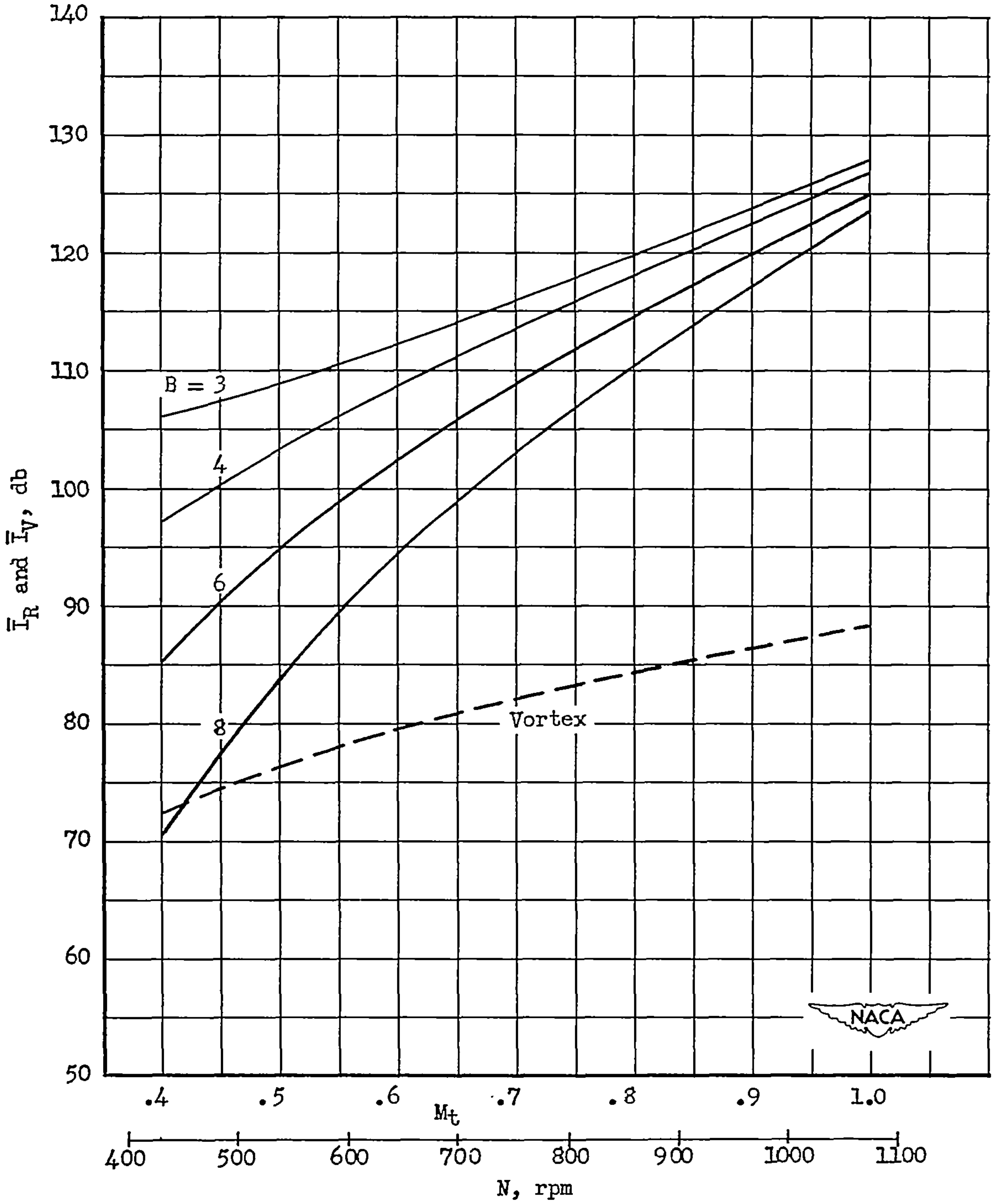
(b) D = 12 feet.

Figure 7.- Continued.



(c) D = 16 feet.

Figure 7.- Continued.



(d) D = 20 feet.

Figure 7.- Concluded.

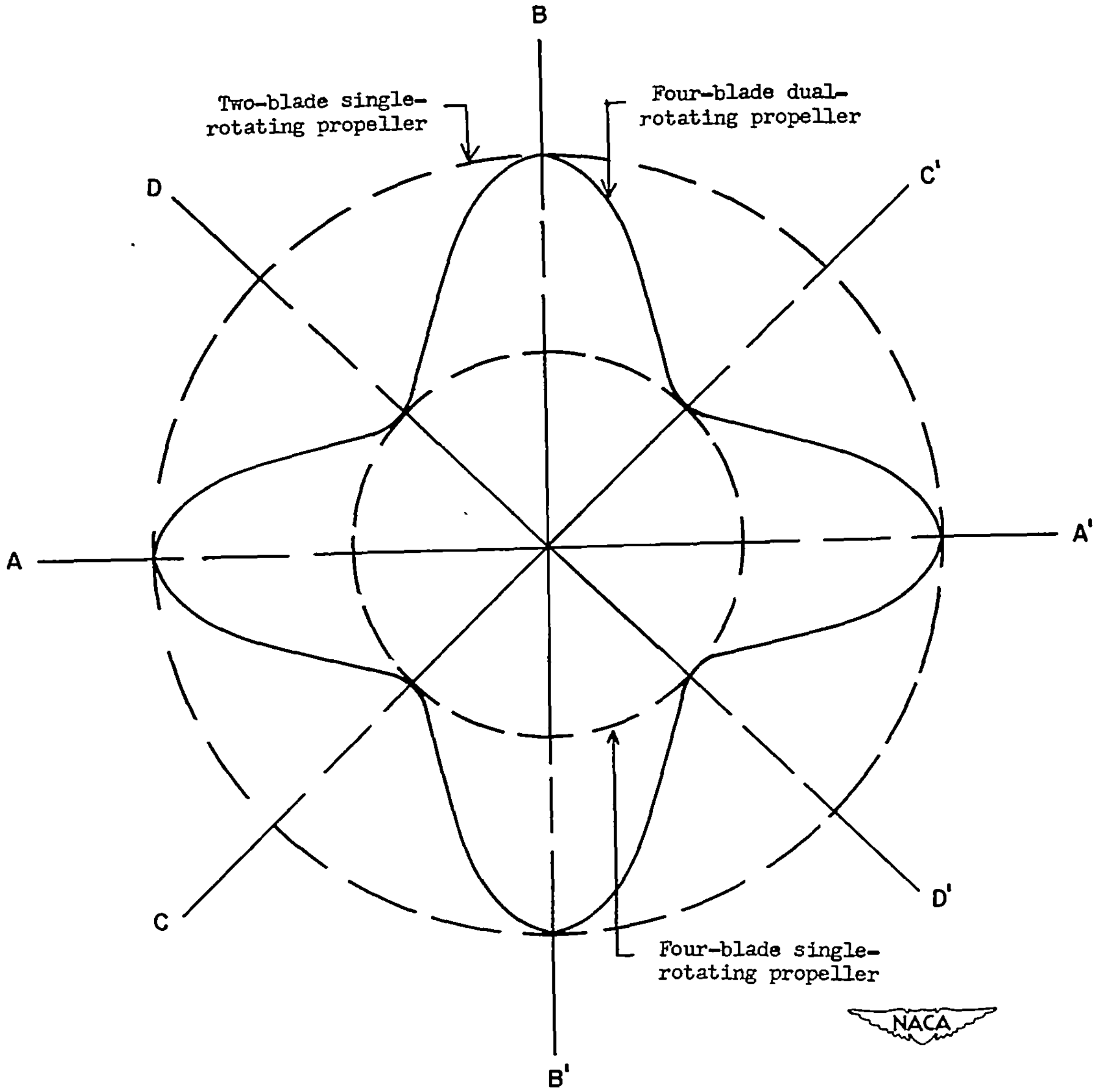


Figure 8.- Free-space radiation pattern in the plane of rotation of three different propellers at the same power and tip Mach number.

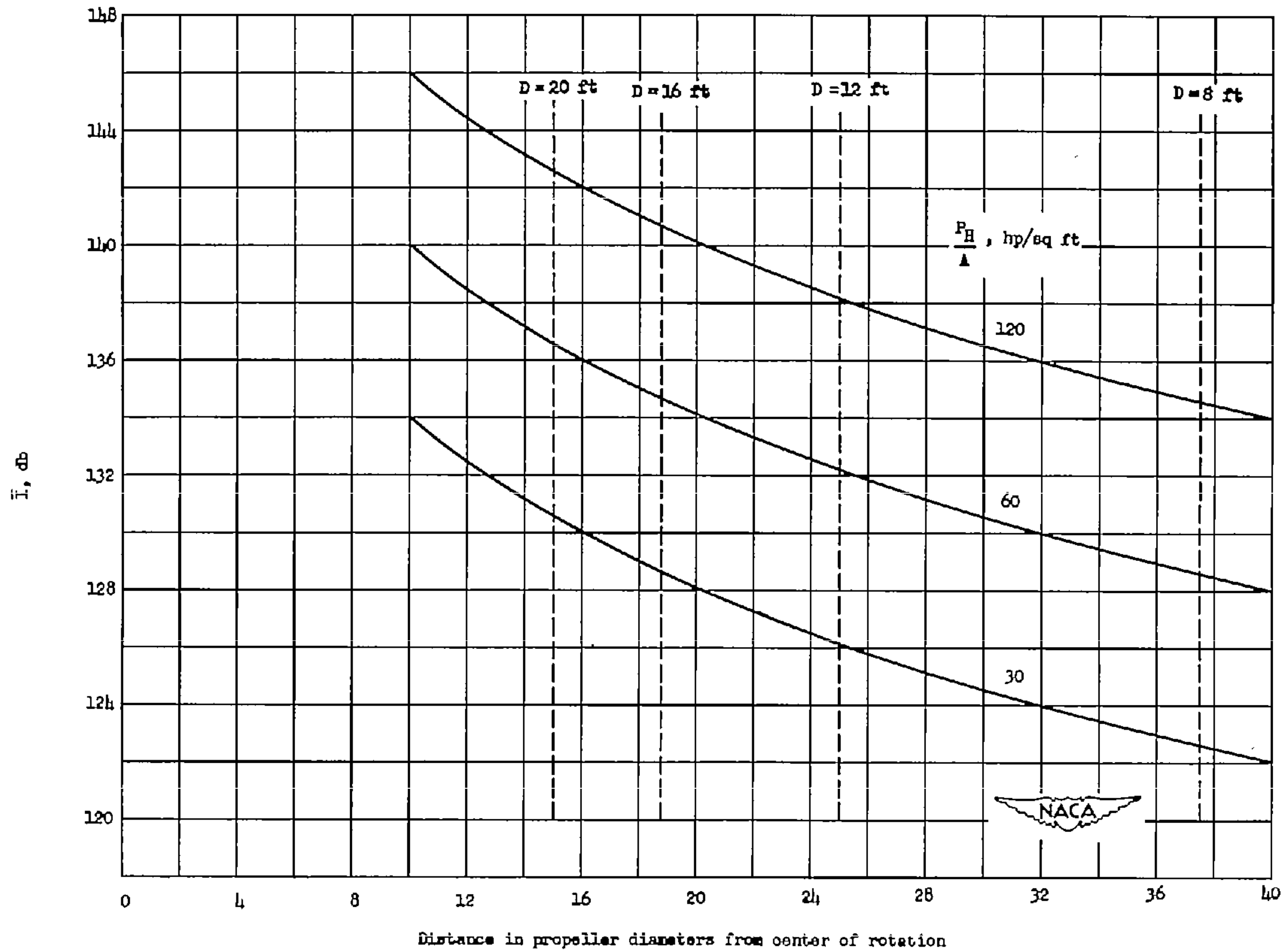


Figure 9.- Chart for estimating the over-all noise from supersonic-type propellers. (Dashed lines indicate distances of 300 feet for four different values of propeller diameter.)

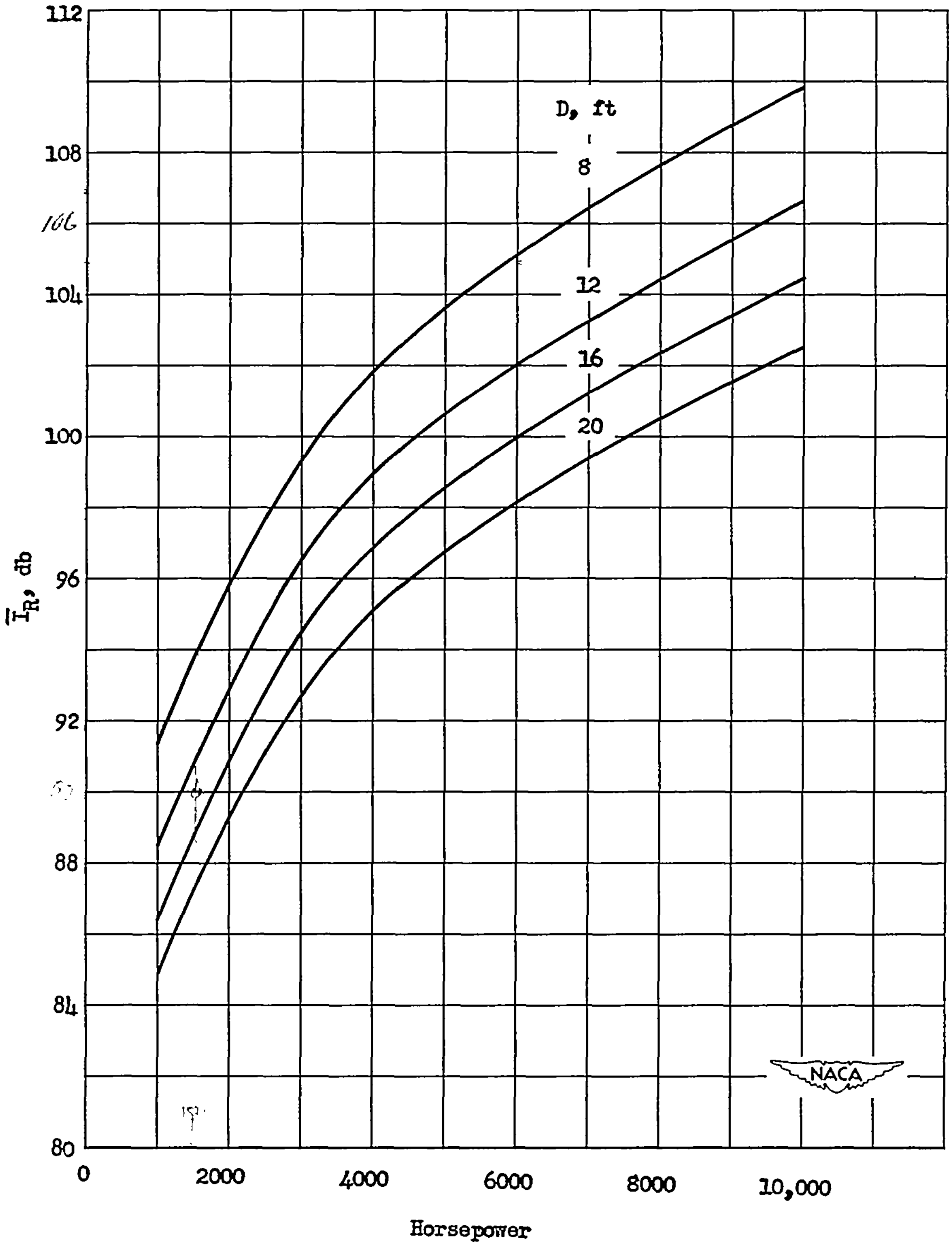


Figure 10.- Sound-pressure level of propeller rotational noise as a function of power input and diameter. B = 6; M_t = 0.6; s = 300 feet.

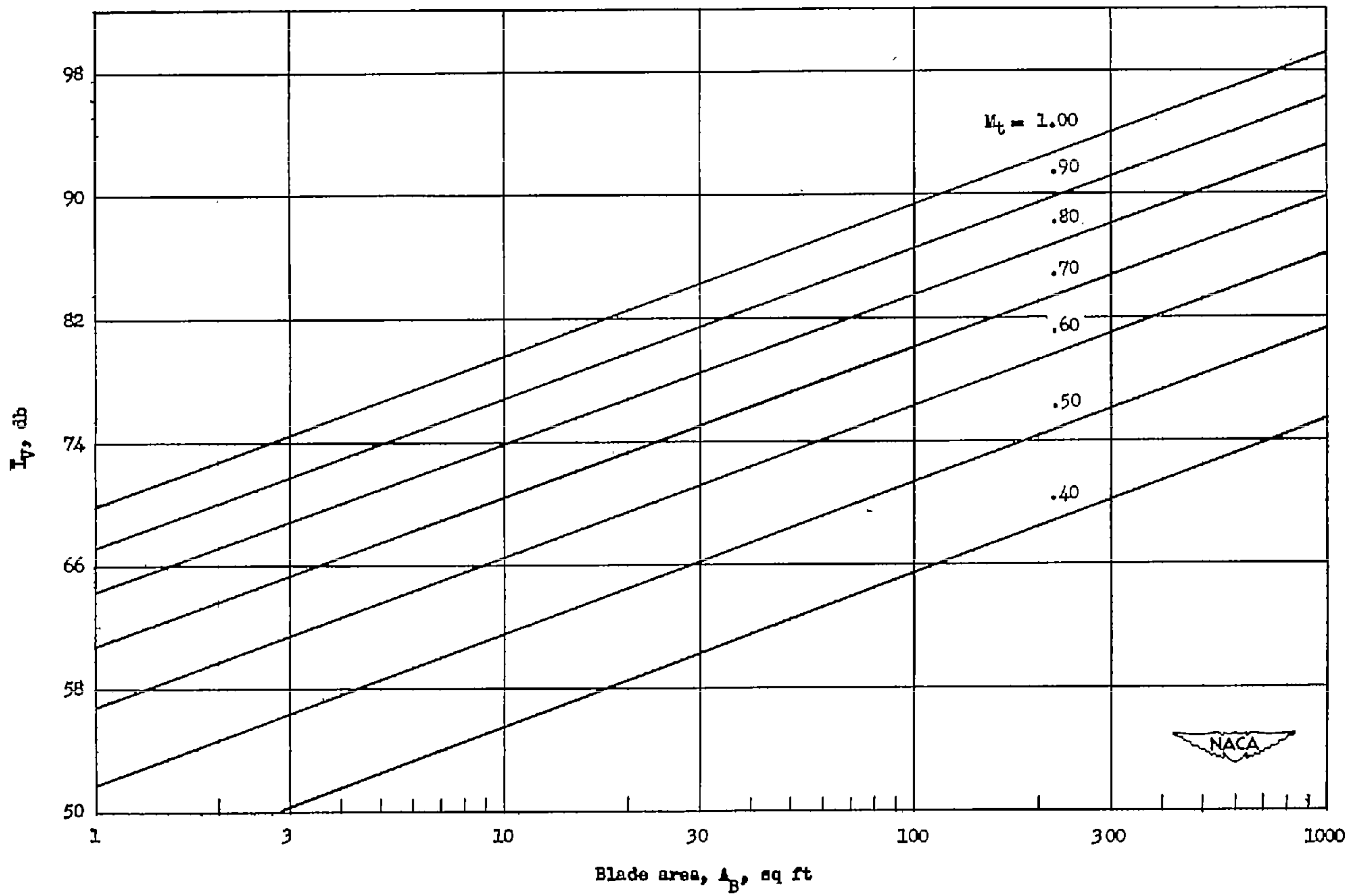


Figure 11.- Sound-pressure levels of vortex noise as a function of propeller-blade area and tip Mach number.

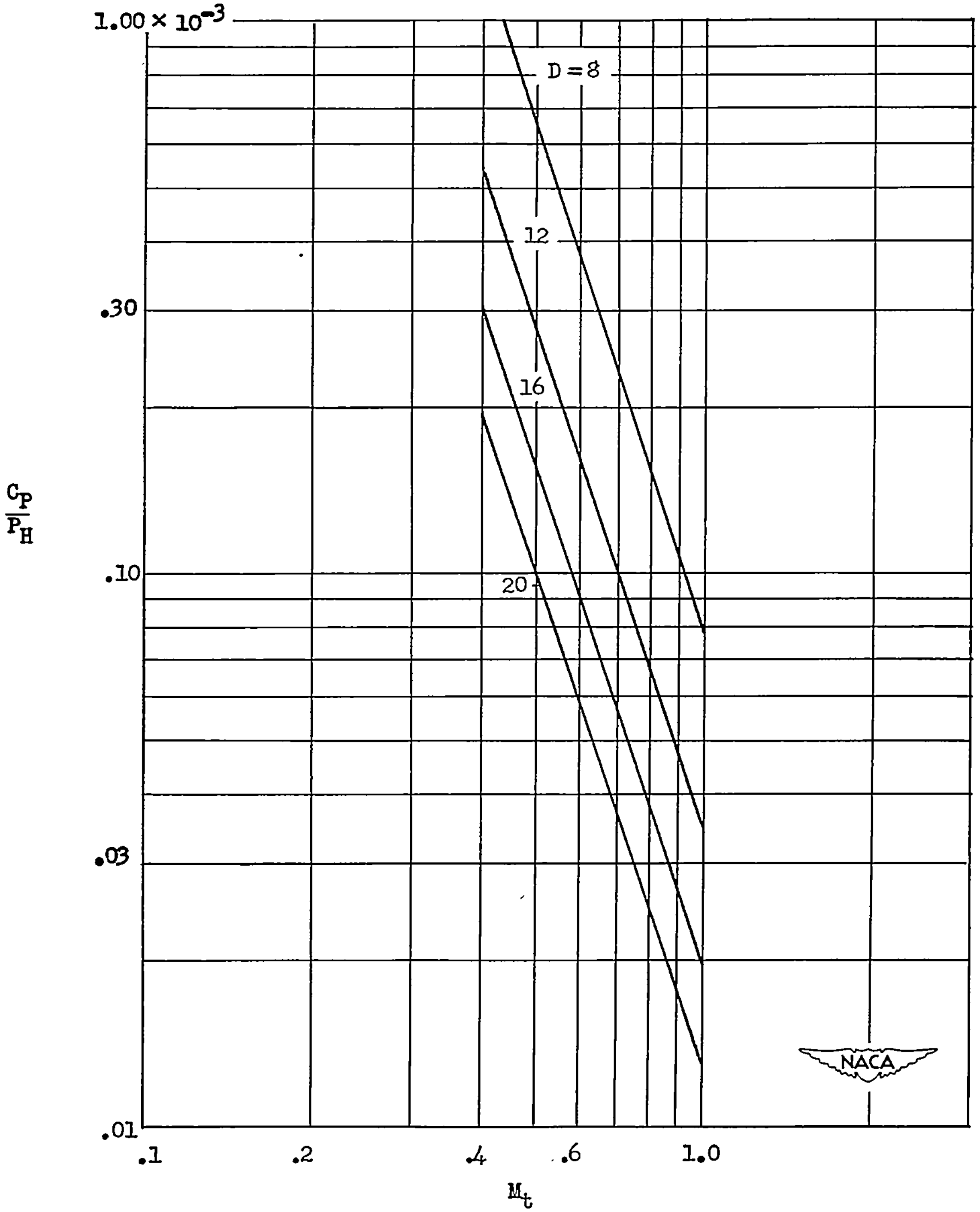
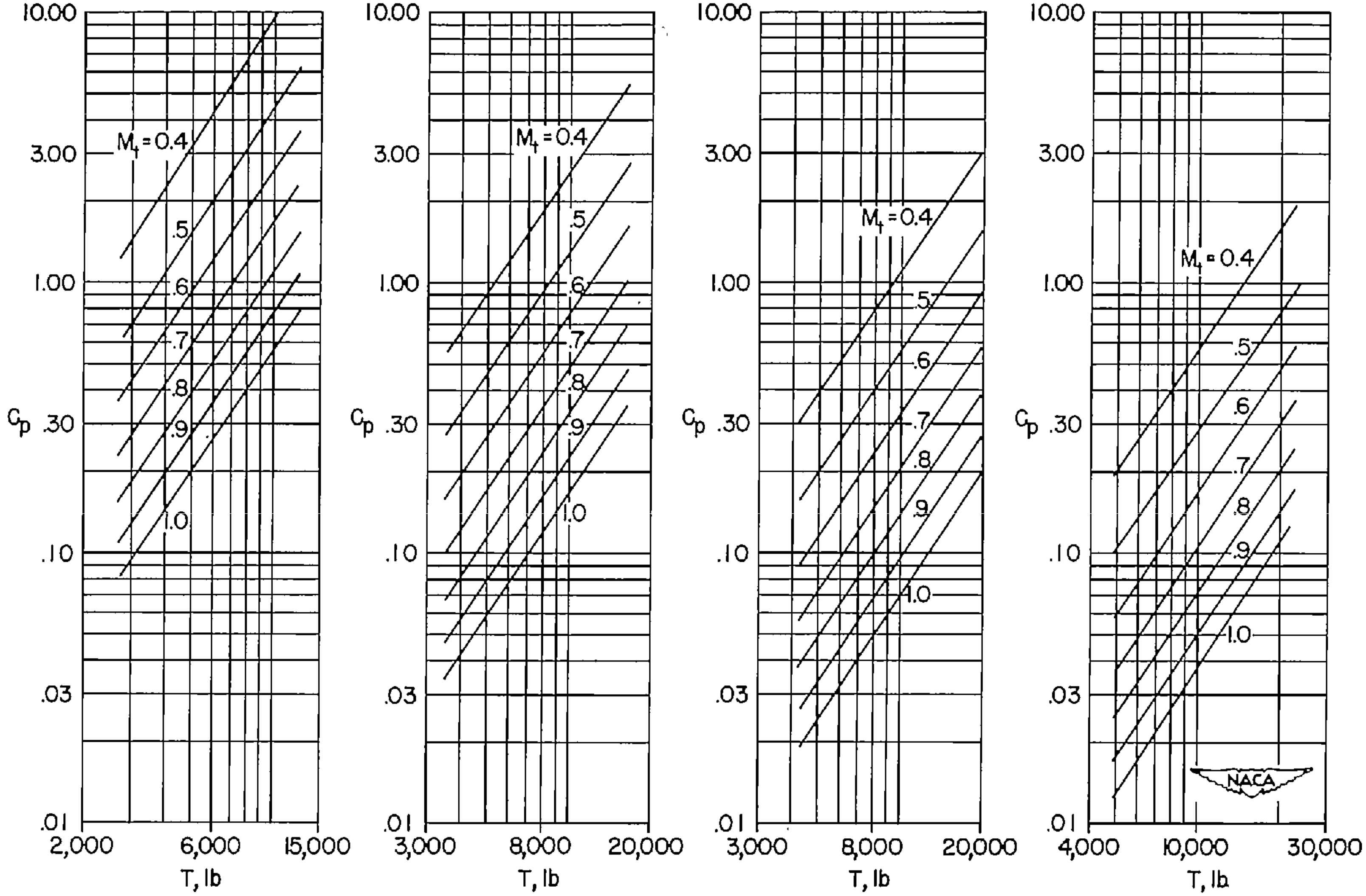


Figure 12.- Power coefficient per unit horsepower as a function of tip Mach number and propeller diameter. ρ = 0.002378 slugs per cubic foot.



(a) D = 8 feet. (b) D = 12 feet. (c) D = 16 feet. (d) D = 20 feet.

Figure 13.- Static thrust for a given power coefficient as a function of tip Mach number and propeller diameter.

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